Comparison on perception of envelope and temporal fine structure cues in unaided and aided conditions using Kannada chimeric sentences

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May 2019

CERTIFICATE

This is to certify that this dissertation entitled **"Comparison on perception of envelope and temporal fine structure cues in unaided and aided conditions using Kannada chimeric sentences"** is the bonafide work submitted in part fulfillment for the degree of Master of Science (Audiology) of the student Registration Number: 17AUD037. This has been carried out under the guidance of the faculty of the institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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This is to certify that this dissertation entitled **"Comparison on perception of envelope and temporal fine structure cues in unaided and aided conditions using Kannada chimeric sentences"** has been prepared under my supervision and guidance. It is also being certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled **"Comparison on perception of envelope and temporal fine structure cues in unaided and aided conditions using Kannada chimeric sentences"** is the result of my own study under the guidance of Dr Devi N, Reader in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru **Registration No: 17AUD037**

May, 2019

Dedication

வீரத்தமிழ்....பாரில்.....கவி வேரில்!!!

தன் உதிரத்தை

எனக்கு உரமாக்கிய

என் உணர்வுக்கு

சமர்ப்பணம்!!!!

Acknowledgment

"Feeling **gratitude** and not expressing it is like wrapping a present and not **giving** it." "There is always something to be thankful for." "Not what we say about our knowledge we gain, but how we use them, is the true measure of our **thanksgiving**."

I am grateful to be a part of AIISH; an archive of knowledge taught me to learn from my mistakes and made me evolve into a human with patience and being persistent. I would like to extend my gratitude toward my guide, an ideal teacher, impeccable supporter, **Dr. Devi. N** for inspiring hope, ignite my mind and instil a love towards learning and Audiology in me. Providing a platform to grow and accomplish is boundless, I would like to thank my beloved director of this institute **Dr. M. Pushpavathi** for providing me this opportunity to enrich my knowledge in research, HOD of Audiology **Dr. Sujeet Kumar Sinha** for allowing me to utilise the resources of the department, **Mr. Ravi and Mr. Ravi Shankar** from Department of Electronics for imparting me the technical support for my dissertation. I am thankful to **Mr. Udhay kumar** for sharing his knowledge. I sincerely thank all the participants, for their volunteer and whole hearted participation in my study.

Some personalities in the journey of life are so inspiring, they enlighten our mind to follow our passion and build confidence in carrier. I am extremely indebted to **Professor Asha Yathiraj** for bringing interest in speech perception and **Professor Animesh Barman** for imparting curiosity in psychophysics in me.

“Family is not an important thing. It’s everything.” Family provides roots to stand tall and strong, I am very thankful to my roots for shredding me as their offspring and shading me with love and support.

A friend is a one who walks in and stay in our life when rest of the world walks out. I am lucky for my dear friends **SKYLTS** and **Roshi** who got into my life and still staying in my soul. Friends are not meant for being grateful, they are destined to cherish through the life. When acquaintances turn into best friends, we don’t need anything else to pass on the days. **Sundari gals(girls), Sanket, Satish, Biswajit, Kishore, Ajay, Amit, Kriti** and **the 40Hz**, I am very much fortunate to have you all during my days in AIISH and I wish this to continue forever. I am obliged to have **Sonia** and **Kamal** as my dissertation partners. I specially thank **Neha** for being my lucky partner in data collection.

I extend my sense of gratitude to one and all, who directly or indirectly have lent their hand in this piece of work.

Abstract

Individuals with sensory neural hearing loss have difficulty in perceiving temporal fine structure and envelope cues of the speech. A hearing aid amplifies the speech signal and makes it audible for the individual with hearing loss. Ideally hearing aid amplification should improve the audibility without detreating the speech signal so that speech perception of individuals with hearing loss improves with hearing aid. To assess this, perception of envelope and fine structure cues with a hearing aid in individuals with hearing impairment was studied with Kannada chimeric sentences. Chimeric sentences were constructed with envelope and fine structure cues of different sentences using Hilbert transform with 1, 4, 6, 13, 16, 28, 32 & 64 frequency bands in MATLAB software. 20 ears (15 individuals) ranging in age from 18 to 40 years were involved in a sentence identification task using Kannada chimeric sentences in unaided and aided conditions at a comfortable presentation level. The scores for fine structure cues were zero across all number of frequency band in both unaided and aided conditions. Results revealed that in both unaided and aided conditions, there was a significant difference in perception of envelope cues across frequency bands and the influence of a number of frequency band on the performance of envelope cues perception was different between unaided and aided conditions. The scores for the perception of envelope cues were significantly different between unaided and aided condition across all number of frequency bands except with 6 frequency bands. So, it can be concluded from this study that aiding an individual with an appropriate hearing aid will influence the perception of envelope cues of speech and it would improve the performance.

Table of Contents

List of tables ... i

List of figures ... ii

Chapter 1 ...

Introduction ... 1

Chapter 2 ...

Review of literature ... 6

Chapter 3 ...

Method ... 13

Chapter 4 ...

Results ... 19

Chapter 5 ...

Discussion ... 26

Chapter 6 ...

Summary and conclusion ... 31

References ... 35

List of tables

Table No	Title	Page No
4.1.	Average raw scores for perception of envelope and fine structure cues across different no. of frequency bands in unaided and aided conditions	20
4.2.	Mean, SD and Median of scores for perception of envelope cues across different no. of frequency bands in unaided and aided conditions	20
4.3.	Results of Friedman test for comparison on perception of envelope cues across a different number of frequency bands in unaided and aided conditions	22
4.4.	Results of Wilcoxon pairwise comparison on perception of envelope cues across different number of frequency bands for unaided condition	23
4.5.	Results of Wilcoxon pairwise comparison on perception of envelope cues across different number of frequency bands for aided condition	24
4.6.	Results Wilcoxon signed rank test to compare the perception of envelope cues between unaided and aided conditions	25

List of figures

Figure No	Title	Page No
3.1	Diagrammatic representation of the preparation of chimeric stimuli	17
4.1	Median scores for perception of envelope cues across different no. of frequency bands in unaided and aided conditions	21

Chapter 1

Introduction

The peripheral auditory system behaves as if it contains a bank of band-pass filters, with overlapping passbands. These filters are now called "Auditory filters" (Fletcher, 1940; Helmholtz, 1863). Cochlea analyses a complex broadband signal with a series of bandpass filters, wherein each filter corresponds to a particular position along the basilar membrane. Such a process of auditory analysis is referred to as short term Fourier analysis. Fourier analysis represents the signal in terms of its spectral magnitude and phase. Spectral magnitudes have been considered to be important for perception, but the phase of the signal is also important for the perception of the signal (Moore, 2002).

Auditory filters of cochlea decompose complex broadband sounds into a series of narrowband signals which consist of the slowly varying envelope (E) overlaid on rapidly varying temporal fine structure (TFS). Both E and TFS information is coded as temporal properties of neural discharges where TFS information depends on neural phase locking to individual cycles of the stimulus waveform. TFS cues are essential for masking, pitch perception, and speech perception. TFS may be especially important for the ability to “listen in the dips” of fluctuating background sounds for detecting non-speech and speech signals. Evidence in the literature suggests that cochlear hearing loss reduces the ability to use TFS cues (Moore, 2008).

Several researches have been conducted to investigate the role of E and TFS cues in speech perception by processing speech sounds so that they contain either E or TFS cues. Dudley (1958) used different forms of vocoders for this purpose. Speech processed to have only E cues using vocoders are referred to as “E-speech”. E-speech processed with a few bands has yielded good intelligibility for speech in quiet (Shannon et al., 1995), whereas more bands are required to attain intelligibility in the presence of background sounds (Qin & Oxenham, 2005; Stone & Moore, 2003). Overall, the results suggest that E cues are sufficient to give good intelligibility for speech in quiet, but they are not sufficient when background sounds are present, especially when the background is fluctuating.

During the processing of the acoustic signal, the envelope cues and fine structure cues have its own relative contribution in identifying the signal. However, special algorithms are required in order to understand the individual contribution of each cue in the auditory processing of the signal. Earlier studies have used methods such as peak clipping where there is an increase in impairment of speech intelligibility (Licklider & Pollack, 1948) and Hilbert transform method (Bracewell & Bracewell, 1986) to separate the TFS and E cues in a signal to study perceptual significance of the E and TFS cues by constructing hybrid sound known as the ‘Auditory chimeras’. Chimeric sentences are developed by interchanging the TFS and E cues of two different sentences and hence help us in understanding the importance of perceiving each sound. Shannon et al. (1995) demonstrated that for normal hearing individual E cues are important for speech perception and also provides robust support that it is sufficient for speech identification in quiet when only as few as four frequency bands are provided. On the other hand, TFS cues have their relative importance in the perception of the pitch; lexical tone and also the speech in a noisy environment. Thus, auditory chimeric sentences provide a significant way to study on the relative importance of E and TFS cues in pitch and speech perception.

Smith et al, (2002) found that in the case of speech, 4 – 16 frequency bands are essential to identify words represented by the envelope than the fine structure. But in the case of hearing-impaired individuals studies have revealed that cochlear hearing loss in adults affects the ability to encode and/or use TFS cues rather preserving the ability to encode the E cues (Lorenzie et al., 2006). On the other hand in individuals with central damage and specific language acquisition disorder studies report that there is impairment in the perception of envelope cuessss (Lorenzi, Dumont & Fullgrade, 2000; Giraud et al., 2000).

Need for the study

The effect of the envelope and fine structure cues in normal hearing individuals especially in foreign tonal such as Mandarin Chinese was studied and found that in tonal languages TFS plays important role in the perception (Xu & Pfingst, 2003). Smith et al, (2002) also reported that the non-tonal language was governed by the envelope (E) cues however tonal language was governed by the temporal fine structure (TFS) cues in the normal hearing individual. Studies were done on south Indian languages such as Malayalam and Kannada using chimeric sentences. In Malayalam, the speech stimulus with the lower bands was identified with TFS cues whereas speech stimulus with the higher bands used E cues (Indu, 2016). However, when Kannada chimeric words and sentences were used, the results revealed that envelope cues were employed majorly than fine structure cues (Naveen, 2017). As divergent results have been reported in different languages there is a need to investigate the relative importance of cues in each of these languages separately. In the case of individuals with hearing loss of cochlear origin, studies had revealed that the individual with hearing loss had difficulty in encoding TFS cues because of the impaired phase-locking abilities. Buss et al., (2004) also supported that individuals with sensorineural hearing loss had reduced ability in encoding TFS cues due to impaired phase locking. Hopkins et al., (2008) had concluded that individuals with moderate cochlear hearing loss have reduced ability to use the TFS cues to understand speech both in the quiet and noisy situation. Vinayagar (2018) compared the importance of E and TFS cues in speech perception using processed Kannada Chimeric sentences across different frequency bands for a simulated moderately flat sensorineural hearing loss. The results showed E cues being perceived better with an increase in the frequency band with TFS cue predominant with the low-frequency band. This study was mainly carried out on normal hearing individuals with simulated processed stimuli, so there is a need to assess the same in individuals using hearing aids. Preserved envelop and TFS cues are essential for a hearing aid to provide good speech perception for the users. Gatehouse (1994) suggested that hearing aid benefits also depends on psychophysical properties of speech that were amplified by the hearing aid. Hence, it is crucial to analyze the perception of E and TFS cues in aided and unaided conditions, so the importance of those cues in speech perception by hearing aid users and the benefit from hearing aid can be assessed.

Aim

The aim of the study was to compare the perception of Envelope and Temporal Fine structure cues in unaided and aided condition using Kannada chimeric sentences.

Objectives

- To establish the number of frequency bands required to perceive the envelope and fine structure cues in unaided and aided conditions with Kannada chimeric sentences.

- To compare the influence of envelope cues in aided and unaided condition, using Kannada chimeric sentences.
- To compare the influence of fine structure cues in aided and unaided condition, using Kannada chimeric sentences.

Hypothesis

The following null hypotheses were framed for each objective of the study.

- There is no effect of number of frequency bands in the perception of envelope and fine structure cues in both the conditions using Kannada chimeric sentences.
- There is no influence of envelope cues in aided and unaided condition, using Kannada chimeric sentences.
- There is no influence of fine structure cues in aided and unaided condition, using Kannada chimeric sentences.

Chapter 2

Review of literature

Psychophysical measures such as detection of 2 Hz frequency modulation (FM) and the discrimination of the rate of amplitude modulation (AM) and quasi-frequency modulation (QFM) were thought to reflect perception of temporal fine structures in speech by individual with sensory neural hearing loss. Buss et al., (2004) tested word recognition and psychophysical measures which involved frequency modulation in 14 individuals ranging in age from 19 to 48 years with normal hearing and 12 individuals with mild to moderate sensory neural hearing loss. It was found that listeners with sensorineural hearing loss poorly performed in the psychophysical tasks which correlated with poorer word recognition. This reflected that individuals with sensorineural hearing loss had a poor perception of fine structure cues in speech. This was attributed to poorer neural phase locking which is essential for speech encoding. Similarly, Lorenzi et al., (2006) reported that people with sensory-neural hearing loss have difficulty in speech perception especially in the presence of background noise. This was related to a lack of fine structure perception by hearing-impaired people who might have reduced the advantage provided by fine structure to listen in background dips.

There are other studies in the literature which support the prediction that hearing impaired has a poor perception of temporal fine structures: Hopkins & Moore (2007) have reported that the ddiscrimination task involving a harmonic complex tone was carried out on seven individuals with moderate cochlear hearing loss. Hearing impaired subject poorly performed in the discrimination task suggesting that they could not access the temporal fine structures of the harmonics. Whenever the stimuli is shaped in such way that it has higher harmonics which falls in the frequency where hearing loss is more than 30dB, subjects performed poorly in the psychophysical tasks so, subjects with moderate cochlear hearing loss make little use of temporal fine structure information for unresolved components. Poor frequency resolution in cochlear hearing loss is attributed to this. However, some subjects performed fairly when a stimulus is shaped to have lower harmonics which falls in the frequency range where the hearing sensitivity was better. So, it was evident that hearing loss of moderate or more than that will exhibit poor perception of temporal fine structures.

Hopkins, Moore and Stone (2008) reported the speech recognition thresholds in the presence of multi-talker babble for nine individuals ranging in age from 26 to 79 years with moderate hearing loss. Varying amount of temporal fine structures was provided in the speech using bandpass filters and vocoders. Even with additional fine structure cues hearing impaired listener performed poorly than normal hearing listener which suggested that the reduced ability to take advantage of TFS information in speech may partially explain why subjects with cochlear hearing loss get less benefit from listening in a fluctuating background than normal-hearing subjects. TFS information may be important in identifying the temporal “dips” in such a background.

A review by Moore (2008) on importance of envelope and fine structure cues in masking pitch perception and speech perception revealed that both the cues are temporally coded in the auditory system wherein fine structure cues require temporal phase locking for its percept. It was found that cochlear hearing loss reduces the ability to use TFS cues which was reflected in poorly derived TFS cues in tasks involving masking, pitch perception and speech perception.

TFS processing and speech processing was assessed by Strelcyk & Dau (2009) in ten sensorineural hearing-impaired listeners with similar high-frequency hearing loss. TFS processing was assessed with binaural masked detection, tone lateralization in quiet, tone lateralization in noise monaural frequency modulation detection in quiet and monaural frequency modulation detection in noise. Speech reception threshold for the sentence was measured for unfiltered and low pass-filtered sentences in the presence of interferers. It was found that hearing-impaired listeners performed poorly than normal in terms of TFS processing and speech perception, also it was found that the effect of noise on TFS processing was much smaller for the hearing impaired listeners than for the normal listeners and performance on TFS processing was correlated with speech reception in a two-talker background and lateralized noise, but not in amplitude-modulated noise. So, the acuity of temporal fine structure processing was decreased for the hearing impaired listeners; it seemed to be as robust to noise interference as for the normal hearing listeners.

Speech reception threshold (SRT) of sensorineural hearing-impaired subjects was measured by Hopkins and Moore (2010) with speech material processed with different amount of TFS cues. It was found that SRT positively correlated with the amount of TFS cues present in the target and competing for speech babble but the improvement in SRT with improved TFS cue was lesser when compared with that of a normal hearing individual’s performance. Hearing-impaired subjects benefited less, although the benefit varied across subjects, from TFS information in speech which was correlated with a psychophysical measure of TFS sensitivity.

Five individuals with mild to moderate sensorineural hearing loss participated in an experiment conducted by Ardoint, Sheft, Fleuriot, Garnier and Lorenzi (2010), assessing the effect of TFS cues in consonant identification. The temporal envelope was removed from the stimuli preserving TFS. Results reflected that hearing impaired can perceive consonant through preserved TFS but poorer than the normal hearing individual. For mild to moderate levels of hearing loss, cochlear damage reduces but does not abolish the ability to use the TFS cues of speech. The deficits observed in hearing-impaired listeners suggest the involvement of factors other than only poor reconstruction of temporal envelope from temporal fine structure.

Combinations of features from different sounds have been used in the past to produce new, hybrid sounds for use in electronic music. Auditory chimeras are hybrid sounds synthesized with temporal envelope and fine structure from different sounds. Auditory chimeras were extensively used in past research studies to evaluate the importance of temporal cues in auditory perception.

Smith, Delgutte and Oxenham (2002) used speech-noise chimeras and speech-speech chimeras to explore how important the envelope and fine structures are for speech perception. When speech noise chimeras were used, it was found that target words containing envelope cues were better identified by six Native American speakers with frequency bands four or more, but target words with fine structure cues were better identified with lesser bands such as one or two. When speech-speech chimeras were used target words with envelopes cues were predominantly perceived by the participants with 4 to 16 frequency bands over target words with fine structure cues. In the same study when melody-melody chimeras were used for pitch perception task, the pitch of melodies with fine structure cues was predominantly perceived till 32 frequency bands whereas the pitch of melodies with envelope cues was perceived with 48 and 64 frequency bands. It was found that the envelope is important for speech perception and fine structure is important for pitch perception and localization.

Auditory chimeras were also used in literature to investigate the role of temporal envelope and fine structure in lexical tone perception.

Xu and Pfingst (2003) exchanged envelope and fine structure of different tone patterns in Mandarin Chinese monosyllables to synthesize auditory chimeras, which were used to investigate the role of temporal envelope and fine structure in lexical tone perception. Participants were five normal hearing native Chinese Mandarin speakers. Results showed that temporal envelope cues were essential for lexical tone perception when 4, 8 and 16 frequency bands were used.

Liu and Zeng (2006) studied the contribution of temporal envelope and fine structure in clear speech perception. In that experiment auditory chimeras were created by mixing the temporal envelope of clear speech with the temporal fine structure of conversational speech and vice versa. Speech intelligibility was assessed in normal hearing individuals by measuring speech recognition thresholds of the hybrid material at different SNR. The results revealed that at the higher signal to noise ratio temporal envelope contributed more for clear speech perception whereas at a lower signal to noise ratios temporal fine structure’s contribution was more.

Lorenzi, Gilbert, Carn, Garnier and Moore (2006) used envelope alone speech and fine structure alone speech extracted using Hilbert transform to investigate the contribution of both the temporal cues for the perception of speech in the presence of background noise in seven individuals with normal hearing ranging in age from 21 to 35 years and seven individuals with flat moderate sensorineural hearing loss ranging in age from 18 to 39 years. Results showed that individuals with hearing loss have difficulty in perceiving fine structure cues which results in poor speech perception in the presence of background noise. This was because of the inability to use the temporal fine structures which were found to be essential for listening in dips of varying background noise.

Heinz and Swaminathan (2009) gave electrophysiological evidence for the recovered envelope at the cochlear level for fine structure speech, for which they have used chimeric speech. A neural cross-correlation coefficient was developed to quantify the similarities between the neural spike train recorded in the auditory nerve in response to temporal envelope and fine structure separately. Results revealed that recovered envelope was present in recorded spike train from the auditory nerve for one and sixteen frequency bands. The recovered envelope was recorded more with single band chimeric speech which adds evidence for the perceptual studies done previously.

Speech-noise chimeras were used by Ibrahim and Bruce (2011) to explain the perception of temporal fine structure speech. They used different speech-noise chimeras involving envelope and fine structure of speech along with white Gaussian noise and spectrum matched noise. Participants were five individuals with normal hearing in the study. It was found that no. of frequency bands and type of chimera significantly influence the perception and also stated that envelope reconstruction can partially but not fully explain intelligibility of fine structure speech chimeras.

Wirtzfeld, Ibrahim and Bruce (2017) also used speech chimeras to investigate the recovered envelope in fine structure speech chimeras. Participants were five normal-hearing subjects aged 18–21years. The authors have used simulated mean-rate and spike timing neural representations of chimeric speech to quantify the envelope recovery and stated that the mean-rate neural cues from the original ENV and recovered ENV partially accounted for perceptual score variability.

Literatures show evidences for application of auditory chimeras in various psychophysical and speech perception experiments conducted to study the perception of temporal envelope and fine structure information in normal hearing individuals. Also there are evidences for poorer perception of temporal envelope and fine structure information in individuals with hearing loss. So, it is feasible and appropriate to study perception of envelope and fine structure in individuals with hearing loss to compare their unaided and aided performance.

Chapter 3

Method

The present study was aimed to compare the perception of temporal envelope (E) cues and fine structure (TFS) cues of speech in unaided and aided conditions using Kannada chimeric sentences.

3.1 Participant

Twenty ears of 15 naive hearing aid users who are native speakers of Kannada within the age range of 18-40 years (mean age- 31.5 ± 7.02 years) were tested in the study**.**

3.1.1 Inclusion criteria

- Individuals with mild to moderate sensory neural hearing loss.
- Hearing threshold: Air conduction hearing thresholds should be within 26dBHL to 55dBHL at octave frequencies between 250Hz to 8000Hz. Air Bone gap should not be more than 10 dB at octave frequencies between 250Hz to 4000Hz.
- Speech identification scores proportional to the hearing threshold
- Immittance audiometry: 'A' type tympanogram
- Uncomfortable level for speech greater than or equal to 100 dBHL in both ears
- No history or presence of any external or middle ear problem
- No history or presence of any neurological problem
- Native speaker of Kannada
- New hearing aid users who have been fitted with an appropriate hearing aid.

Prior written consent was taken from the participants for their willingness to participate in the study.

3.2 Equipment

The following equipments were used in the study

- A calibrated two channel diagnostic audiometer Garson –Staler model GSI-61 coupled with acoustically matched TDH 39 headphones housed in MX-41/AR and Radio ear B-71 bone vibrator was used to estimate pure-tone threshold, speech recognition thresholds, speech identification thresholds and uncomfortable levels.
- Calibrated middle ear analyser GSI tympstar version 2 was used for tympanometry and reflexometry.
- Otoacoustic measurements were carried out using ILOV 6 equipment.
- A laptop, loaded with the following software:
    - Hilbert transform using MATLAB software [MATLAB 7.12.0 (R2011a)]
    - Vocoder software (serious vocoder developed by Zerius Development Inc) for imposing the vocal effects of speech to another sound.
    - Adobe Audition (version 3.0) was used for the presentation of the stimulus
    - PRAAT (version 6.0.39) software was used for recording the response of the subject
    - NOAH 3.0 was used for programming the hearing aids.
- A 4 channel hearing aid with 6.5 KHz bandwidth and 4 fitting bands was used for all the participants.

3.3 Testing environment

All audiological tests will be carried out in a sound-treated double room where the noise levels are per ANSI, 1999.

3.4 Stimuli

The chimeric sentence list was prepared by using the sentences from the "Sentence list in Kannada" (Geetha et al., 2014) which has 25 lists of sentences with 40 key words in each list. These sentences list were standardized and validated in normal hearing and hearing impaired population. 16 lists were randomly selected; each list had 10 sentences with 4 key words in each sentence.

3.5 Procedure

The experiment was carried out in 2 phases.

Phase I: Preparation of speech - speech chimera sentences in Kannada

Phase II: Assessment of Kannada chimeric sentences in naïve hearing aid users with and without hearing aid

3.5.1 Phase 1: Preparation of speech - speech chimera sentences in Kannada

- Randomly, 8 lists were assigned for E cues and 8 were assigned for TFS cues.
- The envelopes & fine structures of these sentences were extracted using Hilbert transform and it was interchanged to obtain speech –speech chimeras.
- Hilbert transform was used to extract envelope as a function of the instantaneous amplitude of the signal. It incorporates a filter which will not affect the gain (Yost, Fay & Popper, 2007).

Figure 3.1 shows the process behind the computation of Hilbert transform. The steps involved are as follows:

- First, the system calculates the Fourier transform of the given signal x (t).
- Then it rejects the negative frequencies.
- Finally, it calculates the inverse Fourier transform, and the result will be a complex-valued signal where the real and the imaginary parts form a Hilbert-transform pair.

For example: When x (t) is narrow-banded, |z (t)| can be regarded as a slow- varying envelope of x (t) while the phase derivative ∂t [tan−1(y/x)] is an instantaneous frequency. Hilbert transform symbolizes a narrow-band signal in terms of amplitude and frequency modulation. (Shi, Lee, Liu, Yang, & Wang, 2011) After obtaining envelope and fine structure for each sentence, those cues were exchanged with each other in order to make speech-speech chimeras. For example, envelope of a particular sentence is combined with the fine structure of another sentence to make one chimeric sentence. Likewise, cues are exchanged between all sentences and 80 chimeric sentences were made.

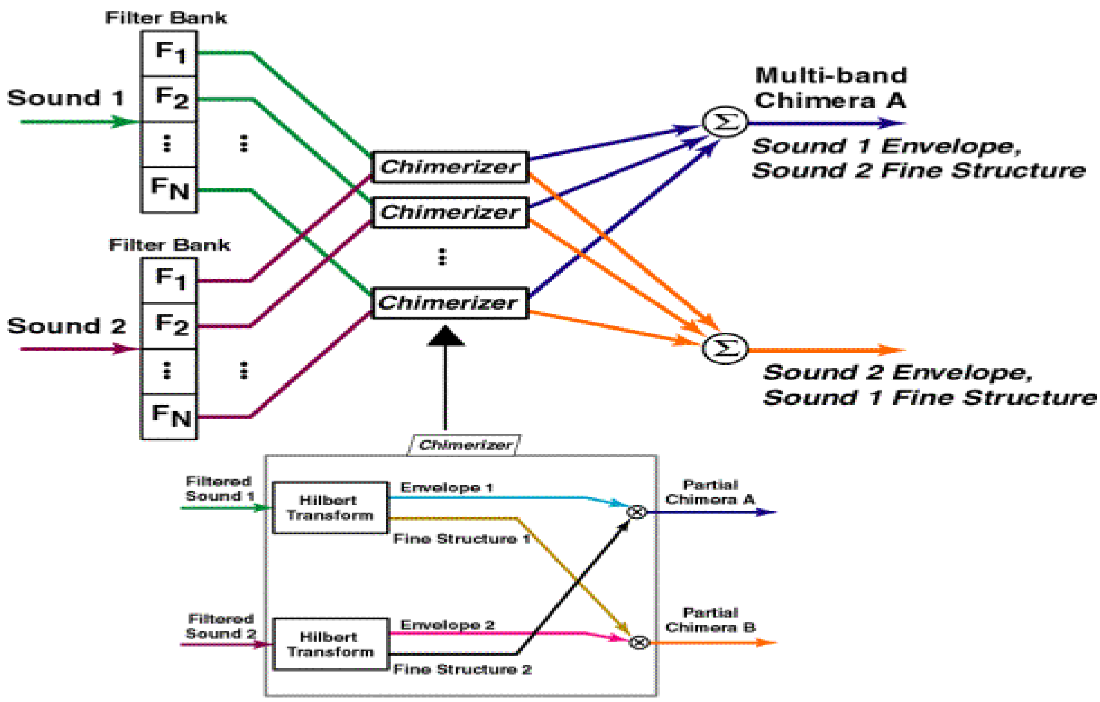

Figure 3.1 Diagrammatic representation of the preparation of chimeric stimuli

Note: Reprinted from Perception of auditory chimeras by Smith, Oxenham and Deglutte (2001) retrieved from *http://research.meei.harvard.edu/chimera/More.html*, Copyright 2001 by Association for Research in Otolaryngology

- Each chimeric sentence was synthesized with 1, 4, 6, 13, 16, 28, 32 and 64 frequency bands and a total of 80 chimeric sentences were created.
- The total numbers of syllables in each sentence were limited to 8 to 9 syllables and each word in a sentence did not have more than 3-4 syllables.
- No sentences were duplicated.

3.5.2 Phase II: Assessment of Kannada chimeric sentences in new naïve hearing aid users with and without hearing aid.

All stimuli were presented through speakers at a comfortable listening level of 65dBHL. Non-test ear better or normal hearing sensitivity was given double protection with silicone impression material and ear muff to avoid its participation. Stimuli were presented in loudspeaker at 45^{o}. Practice sessions were provided using 3 chimeric sentences

- Each participant was provided with 80 chimeric sentences. The participants were asked to repeat the sentence that is perceived and the response was recorded.
- Speech identification was measured based on the number of the content word correctly identified in the sentence initially in unaided condition and later with hearing aid programmed based on NAL NL-1 prescriptive formula appropriate to the type, degree and configuration of individuals hearing acuity
- Scoring was done as the number of word identification which each participant is able to identify from a chimeric sentence. For a particular frequency band in a condition, the minimum score that can be obtained was 0 and the maximum was 40.

Chapter 4

Results

The aims of the present study were to compare the perception of envelope cues and fine structure cues between the unaided and aided condition in hearing-impaired listeners, also to investigate the effect of number of frequency bands on the perception of these temporal cues in unaided and aided conditions. The responses that were recorded for 20 ears with hearing impairment for sentence identification task using Kannada chimeric sentences were analysed by a native Kannada speaker and scoring was carried out. If a keyword from a sentence whose envelope was presented in that particular stimulus was identified then a score of one was given for envelope cues perception, similarly, if a keyword of a sentence whose fine structure was presented in that particular stimulus was identified then a score of one was given to fine structure perception. The responses were scored out of 40 keywords for every frequency bands in each condition (Unaided and Aided). All the collected data were statistically analysed in the SPSS platform version 21.

The average raw scores for the perception of envelope cues and fine structure cues with different number of frequency bands in unaided and aided conditions were tabulated as Table 4.1.

Table 4.1: Average raw scores for perception of envelope cues and fine structure cues across different no. of frequency bands in unaided and aided conditions.

No. of frequency bands	Unaided condition		Aided condition	
	ENV scores	TFS scores	ENV scores	TFS scores
1	0	0	0	0
4	2.10	0	3.55	0
6	10.65	0	12.90	0
13	11.15	0	18.10	0
16	28.90	0	35.40	0
28	31.95	0	36.15	0
32	34.45	0	36.40	0
62	31.25	0	35.45	0

Note: ENV: Envelope cues; TFS: Fine structure cues

It is evident from Table 4.1 that envelope cues was predominantly perceived by the native Kannada speakers with hearing impairment in both unaided and aided conditions but not the fine structure cues. The scores for fine structure cues was zero across different number of frequency bands in both unaided and aided condition. So, further statistical analysis was carried out only for envelope cues.

Descriptive statistics were computed for the obtained data of speech identification scores for envelope cues across different frequency bands. Mean, median and standard deviation for the obtained data were tabulated as Table 4.2.

Table 4.2: Mean, SD and Median of scores for perception of envelope cues across different no. of frequency bands in unaided and aided conditions

No. of frequency bands	Unaided scores			Aided scores		
	Mean	SD	Median	Mean	SD	Median
1	0.00	0.00	0.00	0.00	0.00	0.0000
4	2.10	1.91	2.00	3.55	3.017	3.00
6	10.65	5.45	11.50	12.90	6.29	14.00
13	11.15	7.97	10.00	18.10	7.12	17.50
16	28.90	10.487	30.00	35.40	6.83	39.00
28	31.95	8.178	34.00	36.15	4.34	38.00
32	34.45	7.074	37.50	36.40	5.00	39.50
62	31.25	8.741	33.00	35.45	6.33	36.00

Note: SD: Standard Deviation

Mean and median scores for the perception of envelope cues from Table 4.2 shows that they are different between the unaided and aided condition across different number of frequency bands. Median scores for the perception of envelope cues with different number of frequency bands in unaided and aided conditions were graphically represented in Figure 4.1.

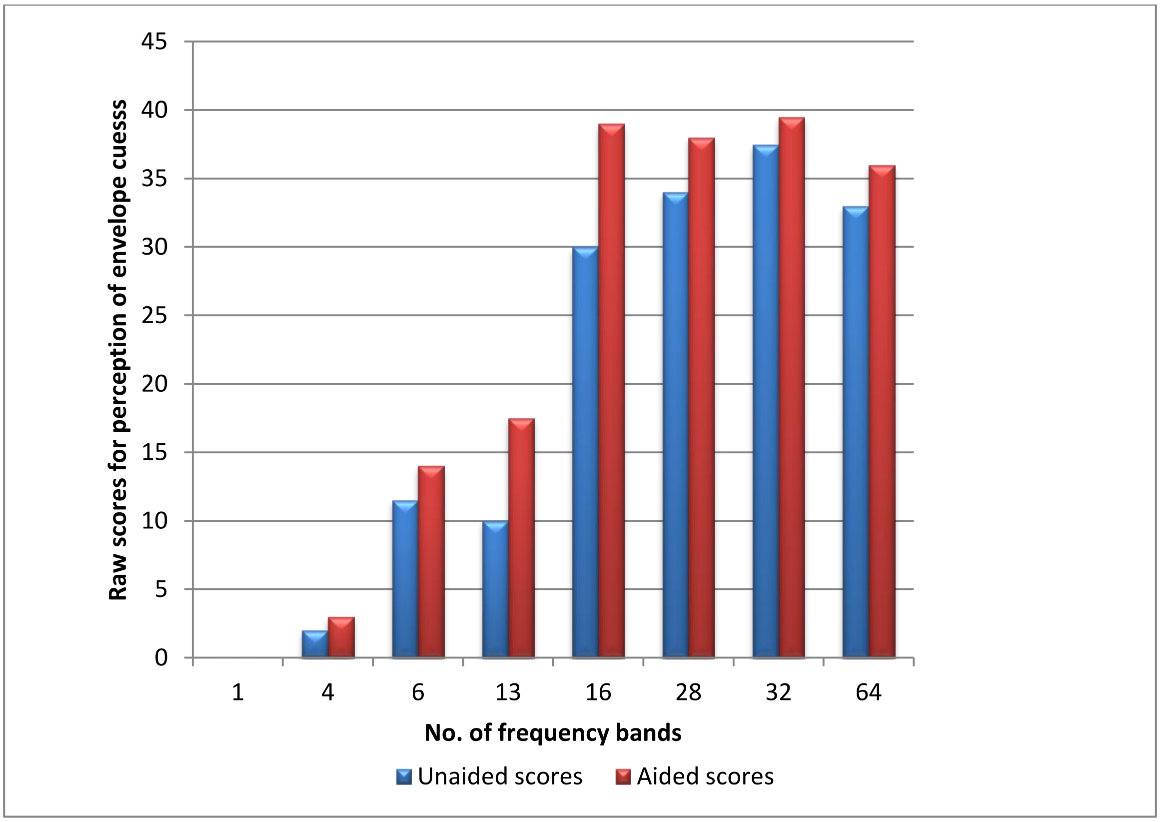

Figure 4.1: Median scores for envelope cues across different no. of frequency bands in unaided and aided conditions

It is evident from the median values depicted in figure 4.1 that scores for envelope cues perception increases as the number of frequency band increase from 1 to 32, but after that, the scores drops at 64 bands in both unaided and aided conditions. Also, there is difference in scores between the unaided and aided condition across different number of frequency bands, wherein aided scores were better than unaided scores.

The obtained data for envelope cues was tested for normality using the Kolmogorov-Smirnov test and Shapiro-Wilk test. It was found that except the scores for 13 bands in aided condition, 6 bands in aided and unaided conditions, other data did not fulfilled the assumptions of normality ($p > 0.05$) and hence non-parametric tests were used.

4.1 Effect of the number of frequency bands on the perception of envelope cues

To evaluate the effect of number of frequency bands on the perception of envelope cues in unaided and aided condition the Friedman test was carried out, which is depicted in Table 4.3.

Table 4.3: Results of Friedman test for comparison on perception of envelope cues across different number of frequency bands in unaided and aided conditions

Condition	**χ2**
Unaided	127.38**
Aided	124.64**

*Note: ** p < 0.01*

It was evident that there was a significant effect of number of frequency bands on the perception of envelope cues in both the conditions. As seen in Figure 4.1, the scores for envelope cues perception improved with increase in the number of frequency bands in both the conditions. So, to estimate the number of frequency bands up to which the performance improves significantly, Wilcoxon pairwise comparison was made between different numbers of frequency bands in both the condition.

Table 4.4: Results of Wilcoxon pairwise comparison on perception of envelope cues across different number of frequency bands for unaided condition

Frequency bands	1	4	6	13	16	28	32	64
1		-3.35**	-3.83**	-3.93**	-3.92**	-3.92**	-3.93**	-3.92**
4			-3.73**	-3.93**	-3.92**	-3.92**	-3.93**	-3.92**
6				-0.03	-3.92**	-3.92**	-3.92**	-3.92**
13					-3.92**	-3.92**	-3.92**	-3.92**
16						-1.81	-3.10**	-1.47
28							-3.24**	-0.31
32								-2.19*
64								

*Note: ** $p < 0.01$; * $p < 0.05$*

Results of Wilcoxon pairwise comparison for the unaided condition is depicted in Table 4.4 reveals that in unaided condition, performance improved significantly ($p < 0.05$) until 32 frequency band and after that the performance drops significantly ($p < 0.05$) at 64 frequency bands.

Table 4.5: Results of Wilcoxon pairwise comparison on perception of envelope cues across different number of frequency bands for aided condition

frequency bands	1	4	6	13	16	28	32	64
1		-3.44*	-3.83**	-3.92**	-3.96**	-3.93**	-3.98**	-3.93**
4			-3.62**	-3.92**	-3.93**	-3.92**	-3.93**	-3.94**
6				-3.46**	-3.92**	-3.92**	-3.92**	-3.92**
13					-3.87**	-3.92**	-3.92**	-3.92**
16						-.10	-.98	-.83
28							-.48	-.67
32								-1.81
64								

*Note: ** p < 0.01; * p < 0.05*

Results of Wilcoxon pairwise comparison for the aided condition is depicted in Table 4.5 reveals in aided condition, the scores significantly ($p < 0.05$) improve till 13 frequency bands and after which there were no significant changes in scores for envelope cues perception. Hence, the null hypothesis that there is no effect of number of frequency bands in the perception of envelope and fine structure cues in both the conditions using Kannada chimeric sentences was rejected.

4.2 Comparison of envelope cues perception between the unaided and aided condition

The Second aim of the current study was to compare the perception envelope cues across different frequency bands between unaided and aided condition. To serve that purpose Wilcoxon signed rank test was carried out to compare scores of sentence identification using Kannada chimeric sentences between the two conditions.

Table 4.6: Results Wilcoxon signed rank test to compare the perception of envelope cues between unaided and aided conditions

No. of frequency bands	**1**	**4**	**6**	**13**	**16**	**28**	**32**	**64**
Z	.00	-2.43**	-1.85	-3.25**	-3.25**	-3.11**	-2.74**	-2.92**

*Note: ** p < 0.01*

Results of Wilcoxon signed rank test is depicted in Table 4.6 shows that except at one and six frequency bands, the performance was significantly ($p < 0.05$) better in aided condition than in unaided conditions. Hence the null hypothesis that there is no influence of envelope cues in aided and unaided condition, using Kannada chimeric sentences, was rejected.

Chapter 5

Discussion

Researches were carried out to evaluate the effect of hearing loss on the perception of temporal cues of speech such as fine structure cues and envelope cues. But there is a dearth in experimental evidences to justify the effect of amplification on the perception of these temporal cues. Hence the current study was done to estimate the effect of hearing aid amplification on the perception of speech through fine structure cues and envelope cues. Various psychophysical means such as vocoders have been used in the past to extract envelope cues and fine structure cues but Hilbert transform algorithm was stated to be accurate in extracting these cues as it derives envelope cues function based on instantaneous amplitude of a signal free of arbitrary parameters and it mainly represents a filter without affecting the gain (Yost, Fay & Popper, 2007). Hilbert transform incorporates Fast Fourier Analysis of the signal to extract the spectral information, which involves bandpass filtering. Various number of frequency bands can be used for that purpose. Based on a speech identification task and its response it can be inferred that a participant perceives either an envelope cues or fine structure cues.

5.1 Perception of fine structure cues in hearing-impaired individuals across different frequency bands in unaided and aided conditions

From chimeras extracted with lesser number of frequency bands such as 1-4, normal hearing individuals can perceive fine structure cues of speech (Smith et al, 2002). Chimerised words with fewer frequency bands such as 1-6 can provide the perception of fine structure cues from speech in normal hearing Kannada speaker and with sentences, frequency band such as 1 can provide fine structure cues perception of speech (Naveen & Devi, 2016). Whereas individual with hearing impairment will have be able to perceiving fine structure cues of speech (Buss et al, 2004; Lorenzi et al., 2006; Hopkins & Moore, 2007; Hopkins, Moore, & Stone, 2008; Moore, 2008; Strelcyk & Dau, 2009; Hopkins & Moore, 2010; Ardoint, Sheft, Fleuriot, Garnier, & Lorenzi, 2010). Similarly, in the current study, scores for the perception of fine structure cues cues across different number of frequency bands were zero in both unaided and aided condition. Hence hearing impaired percieved envelope cuesss rather than fine structure cuess.

5.2 Perception envelope cues in hearing-impaired individuals across different number of frequency bands in unaided and aided conditions

It has been reported by Smith et al, (2002) that 4-16 frequency bands are required to perceive the envelope cues of a speech chimera in non-tonal languages like English. Further, it has been reported that with a fewer number of frequency bands less than 6, rapid changes are speech envelope cues will be missed during processing the stimuli in Hilbert transform algorithm. Hence chimeras prepared with lesser number of frequency bands will have missing envelope cues information. Results of Naveen (2017) are in agreement with this. Perception of fine structure cues and envelope cues from Kannada chimeric sentences and words were assessed in normal hearing Kannada speakers. It has been reported that with lesser number of frequency bands such as one band, fine structure cues was perceived but only a mean score of 3% was obtained, whereas, with more number of frequency bands such as 13, envelope cues were predominantly perceived with a mean score of 60%. So it was evident that number of frequency bands influences the perception of speech envelope cues in normal hearing individual. In this study, the same finding was found that number of frequency band affects the perception of envelope cues in hearing-impaired listeners.

5.2.1 Effect of the number of frequency bands on the perception of envelope cues in the unaided condition

It was found that in the unaided condition, the scores for envelope cues perception improved significantly until 32 frequency bands. To attain a score of more than 50%, 16 frequency bands were required in this study. Comparing this finding with Naveen (2017) finding, it can be inferred that hearing impaired individuals requires more number of frequency bands are required to perceive the same amount of envelope cues that a normal hearing individual perceives. This means, hearing impaired individual require more amount of rapidly varying envelope cues information which will be present with more number of frequency bands. Also, it was found in this study the performance improves even after 16 frequency bands till 32 frequency bands, whereas in Naveen (2017) study reported performance of a normal hearing individual on envelope cues perception didn’t improve with more than 16 frequency bands. Again this supports that hearing impaired individual require more number of frequency bands when compared to that of normal hearing individuals. Another finding of this study was that performance for perception envelope cues drops significantly after 32 bands at 64 bands in unaided condition. This may be attributed to impaired cochlea’s inability to process large varying envelope cues present in chimeras extracted with 64 frequency bands, or it may be due to the temporal distortion caused during processing with too many narrow band filters, but further studies are warranted to ensure this effect.

5.2.2 Effect of number of frequency bands on the perception of envelope cues in the aided condition

In aided condition, perception of envelope cues improved till 16 frequency bands with a mean score of 88.5% after which there was no significant difference in perception of envelope cues. This was similar to the findings of Naveen (2017), so hearing-impaired individuals perceive envelope cues of speech with a trend similar to that of a normal hearing individual's performance. As reported by Naveen (2017), scores for envelope cues perception in normal hearing individuals attained a maximum limit of 100% with 28 frequency bands whereas in this study, performance of hearing impaired for perception of envelope cues was maximally 90% at 28 frequency bands, hence it can be inferred that there exists a difference in envelope cues perception between normal hearing individual and hearing impaired aided with appropriate amplification.

5.3 Comparison of envelope cues perception across frequency band between unaided and aided conditions

Comparing the effect of number of frequency bands on envelope cues perception between unaided and aided condition, it is evident that influence of number for frequency bands on envelope cues perception was different in unaided and aided condition. In unaided condition, even until 32 frequency bands perception of envelope cues significantly improved and in aided condition after 16 frequency bands perception of envelope cues did not improve significantly. The maximum mean score for the perception of envelope cues obtained in unaided condition was 86.2%, whereas in the aided condition it was 91%. So, to establish the difference between unaided and aided condition in terms of envelope cues perception, scores were compared between the conditions across different number of frequency bands. It was found that the perception of envelope cues significantly differed between the unaided and aided condition across different number of frequency bands except with 6 frequency bands. Though there was no significant difference with 6 frequency bands there was a marginal difference noted in the scores between unaided and aided conditions. The chimeric sentences were presented at an intensity level of 20dBSL with reference to speech recognition threshold in both unaided and aided condition; this was expected to control the influence of audibility in the sentence identification task. Still, perception of envelope cues significantly improved in aided condition, so this improvement in perception with appropriate amplification cannot be solely attributed to improved audibility with amplification, rather it was effective audibility shaped and provided by the digital hearing aid through its compression system appropriate for frequency-specific hearing sensitivity of the hearing impaired individual. This can be true because the digital hearing aid used to aid the participants was programmed individually with appropriate gain and compression characteristics.

Chapter 6

Summary and conclusion

Literature shows evidence for the poorer perception of temporal envelope and fine structure cues by an individual with hearing impairment. Digital hearing aids are meant to improve speech perception in individuals with hearing impairment. Temporal cues are essential for speech perception, especially envelope cues is crucial for speech perception in quiet. Various signal processing technologies in a digital hearing aid can cause temporal distortions in the signal it processes. Hence it is important to study the effect of amplification through digital hearing aids on the perception of envelope cues of speech. Auditory chimeras are hybrid signals extracted by using a temporal envelope and fine structures of two different sounds. Speech-speech chimeras are formed by combining the envelope of a particular speech signal with fine structure of another speech signal. Chimeric sentences can be used to study the perception of envelope and fine structure based on the sentences identified on an open set sentence identification task. It was found that a various number of frequency bands are used to chimerize the sentences in Hilbert transform algorithm and it will impact the perception of envelope and fine structure cues from the chimeras. In normal hearing individuals who speak Kannada as their native language, 13 frequency bands are essential to perceive the 50% of envelope cues from Kannada chimeric sentence and also they were not able to perceive fine structure cues predominantly. Hence it was aimed to study the difference in perception of the envelope and fine structure cues between unaided and aided conditions in young adults with mild to moderate sensory neural hearing loss using Kannada chimeric sentences.

Chimeric sentences were constructed using Hilbert Transform algorithm in MATLAB with 1. 4. 6, 13, 16, 28, 32 & 64 frequency bands using recorded Kannada sentences developed by Geetha et al. (2014). A digital hearing aid with 4 channels and 6.5 KHz bandwidth programmed based on individual subject's hearing loss and configuration for 20 ears with mild to moderate sensory neural hearing loss using NAL NL-1 prescriptive formula. An open-set sentence identification task was carried out in the sound field with a loud speaker placed at 45^0 using 80 Kannada chimeric sentences (10 at each number of frequency bands) in unaided condition at a presentation level of 20 dBSL (Ref: SRT). A similar task was carried out in the aided condition. Responses were recorded and scored out of 40 keyword in each number of frequency band.

Scores for the perception of fine structure cues were found to be zero across different number of frequency bands in both unaided and aided condition. Scores for the perception of envelope cues improves till 32 frequency bands and drops at 64 frequency bands in unaided condition. Whereas in aided condition, the score for the perception of envelope improved only till 16 frequency bands and then remained almost the same. The scores for the perception of envelope cues in aided condition were better than unaided condition across different number of frequency bands. Statistical analysis using the Friedmans test shown that there was a significant effect of the number of frequency band in both unaided and aided condition. Wilcoxon pairwise comparison revealed that the scores for envelope cues perception in unaided condition significantly improved till 32 frequency bands and significantly decreases at 64 frequency bands. Scores of aided condition significantly improve till 16 frequency bands and then there was no significant difference. On comparing scores for envelope cues perception between unaided and aided conditions, Wilcoxon sign rank test showed significant differences across all number of frequency bands except at 6 frequency bands, which had a marginal difference but did not attain statistical significance.

In this current study, there was a difference in perception of envelope cues by hearing impaired individuals when compared to an individual with normal hearing in terms of number of frequency bands required to attain 50% of scores when compared to the results of the previous study on normal hearing individuals. Also, the present study showed that aiding a hearing impaired with an appropriate digital hearing aid will improve the perception of envelope cues of speech when compared to unaided performance in terms of sentence identification scores and also number of frequency bands required to attain maximum scores. So, it can be concluded that individuals with hearing impairment have difficulty in perception of envelope cues of speech when compared to that of normal hearing individual. Digital hearing aids, which gives effective amplification according to degree and configuration of hearing loss improves the perception of envelope cues of speech in individuals with mild to moderate sensory neural hearing loss.

Clinical implication

The present study implies that any digital algorithm processing speech signal by bandpass filtering, one such used in current day digital hearing aids will improve the perception of envelope cues from speech if number of frequency bands such as 13 to 16 are used. Because, more the number of frequency bands, narrower the bandwidth, hence small fluctuations in envelope of speech which are important for speech perception can be picked and transformed without disruption. Hilbert transform algorithm has been used in cochlear implants to extract envelope of the signal, similarly, a digital hearing aid with Hilbert transform algorithm can provide better speech perception by providing more accurate envelope cues.

Future directions

- Effect of hearing aid amplification on envelope perception and influence of number of frequency channels on it can be studied in an individual with moderately severe and severe sensory neural hearing loss as they have more difficulty in speech perception.

- Also, the configuration of hearing loss influences speech perception, so the same can be studied in individuals with different configurations of hearing loss.

- It has been found that envelope cues perception is different among Indian languages, so the effect of hearing aid amplification on envelope cues perception in other Indian language speakers.

- Literature states that temporal cues for speech and music perception are different, also hearing aids provided better music and suprasegmental perception than cochlear implants, and so auditory chimeras can be used to verify the same.

- Studies involving acoustic analysis to quantify the difference in envelope cues across different number of frequency bands can provide support to the results found in this study that hearing impaired individual requires more number of frequency bands than normal hearing individuals in both unaided and aided conditions to perceive speech with better accuracy.

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