INFLUENCE OF NUMBER OF FREQUENCY BANDS, ENVELOPE AND FINE STRUCTURE CUES ON PERCEPTION OF TAMIL CHIMERIC SENTENCES

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CERTIFICATE

This is to certify that this dissertation entitled **"Influence of number of frequency bands, envelope and fine structure cues on perception of Tamil chimeric sentences"** is the bonafide work submitted in part fulfilment for the degree of Master of Science (Audiology) of the student Registration Number: 17AUD020. 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.

Mysuru
May, 2019

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CERTIFICATE

This is to certify that this dissertation entitled **"Influence of number of frequency bands, envelope and fine structure cues on perception of Tamil 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 **"Influence of number of frequency bands, envelope and fine structure cues on perception of Tamil 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, Mysuru, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru **Registration No: 17AUD020**

May, 2019

DEDICATION

சமர்ப்பணம்

தாயின் சிறந்த கோவிலும் இல்லை,

தந்தை சொல் மிக்க மந்திரமில்லை,

ஆயிரம் உறவில் பெருமைகள் இல்லை,

அன்னை தந்தையே அன்பின் எல்லை.

என் தாய் தந்தைக்கும், ரத்தத்தின் ரத்தமான என்

உடன்பிறந்த மற்றும் உடன்பிறந்திருக்க

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செய்ந்நன்றி கொன்ற மகற்கு."

- திருவள்ளுவர்.

Who every good have killed, may yet destruction flee;

Who 'benefit' has killed, that man shall ne'er 'scape free!

-Thiruvalluvar.

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Abstract

The temporal cues (envelope and fine structure) play an important role in perception of any speech stimuli. These cues for perception vary with respect to tonality of different languages. Studies have suggested that envelope cues serve as an important cue for perception of non-tonal language and the temporal fine structure cues for perception of tonal language using speech identification task (which included chimeric sentences). However, in Indian context most of the languages particularly, South Indian languages like Kannada and Malayalam are found to be non-tonal. As there is dearth of literature in Tamil language, the current study attempts to investigate the effect of frequency bands and temporal cues (envelope and fine structure cues) on Tamil language using auditory chimera sentences. The present study included 40 native Tamil speaking individuals with normal hearing in the age range of 18 - 30 years. The participants were asked to identify 80 chimeric sentences across eight frequency bands (which included one, four, six, thirteen, sixteen, twenty-eight, thirty-two, and sixty-four). Results revealed that there is an improvement in identification of chimeric sentences as the number of frequency band increased. Also, in comparison with fine structure cue, envelope cue was found to contribute more in identification of chimeric sentences.

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Chapter 1

Introduction

The human auditory system constitutes of three components such as the outer ear, middle ear and inner ear and has the abilities to process complex sound signals. Acoustic energy received by the outer ear will be transferred to the middle ear. This acoustic energy is converted into mechanical energy by the movements of tympanic membrane and ossicles in the middle ear. Further, this mechanical energy will be transferred to the cochlea (inner ear), where the sensory hair cells transduce this mechanical energy into neural activity in the auditory nerve. The neural code in the Auditory Nerve fibers is then borne to higher nuclei in central auditory system for further analysis and processing. (Robles & Ruggero, 2001)

The cochlear mechanism of auditory processing plays a crucial role in speech perception. The cochlea functions like a frequency analyzer in the auditory system, where the frequency content of the signal is mapped into a pattern of excitation on the Basilar Membrane (Chen, Clark, & Jones, 2003). Each place on the cochlea is tuned to a specific frequency called the characteristic frequency (CF), thus the complex sounds are analyzed into a series of band pass-filtered signals (Bekesy, 1960). Two forms of information exist in the analyzed signals. They are fluctuations in Envelop (E) and fluctuations in Temporal Fine Structure (TFS), which are provided by the temporal analysis mechanism (Moore & Sek, 2009). Temporal Fine Structure (TFS) refers to the rapid variations with rates close to the central frequency of the band, whereas envelope (E) refers to slowly varying amplitude superimposed on the fine structure.

There are some specific algorithm used in the previous literature to investigate the relative role of both envelop and fine structure. The first attempt to separate the envelope from a fine structure cue was done using peak clipping mechanism of speech signal (Licklider & Pollack, 1948). However, this mechanism is highly criticized due to the distortion of the speech signals. Later, Hilbert transform (Bracewell & Bracewell, 1986) was used to extract the envelope and fine structure cues from the signals. This method acts like a filter in extracting the temporal cues without affecting the gain (Yost & Fay, 2007). The perceptual relevance of envelop and fine structure cues can be studied by making hybrid sounds known as 'Auditory chimera'. The auditory chimera can be constructed by interchanging the envelope and fine structure extracted from different sentences or words. (Smith et al., 2002).

Perceptual studies on normal auditory system demonstrated that the two cues differently contribute for speech perception. The phase locking property of the auditory nerve fibers codes the TFS information. In spite of the fact that the phase locking is not an important cue at high frequencies there is a loss of synchrony in Mammalian auditory systems for frequencies above 4 - 5 kHz (Palmer & Russell, 1986). So, it can be assumed that "TFS information is not used for frequencies above that limit". The fine structure is important in pitch perception, lexical tone perception and also speech perception in noisy conditions (Smith et al., 2002). It was found that for perception of speech in quiet, envelope cue is sufficient when presented with fewer frequency bands (Flanagan, 1980; Shannon, Zeng, Kamath, Wygonski & Ekelid, 1995; Smith, Delgutte & Oxenham, 2002).

Studies have been conducted to investigate the importance of envelope and fine structure cues in speech perception by individuals with normal hearing and the deviant population. Smith et al, (2002) reported on individuals with normal hearing and found that 4 – 16 frequency bands are essential for the identification of words represented by the envelope than the fine structure. Similar study done in the individuals with hearing impaired, revealed that cochlear hearing loss in adults affects the ability to encode and/or use TFS cues while preserving the ability to encode the E cues (Lorenzie et al, 2006). On the other hand, studies done on individuals with central damage and specific language acquisition disorder reported that there is impairment in the perception of envelope cues (Lorenzie, Dumont & Fullgrabe., 2000; Lorenzie, Wable et al., 2000).

Auditory abilities and speech perception are known to mature over the first 10–12 years (Hnath-Chisolm, Laipply, & Boothroyd, 1998; Siegenthaler, 1969). The developmental trend in the perception of envelope and fine structure cues attracts lot of significance in the speech perception research. However, little work has been done to investigate the developmental time course of the ability to use E and TFS speech cues. Eisenberg, Shannon, Schaefer Martinez, Wygonski, & Boothroyd, (2000) conducted study on 5 – 12 year aged children using noise vocoded speech stimuli, demonstrated that the ability to use E cues in speech matures before the age of 7 years, and becomes adults like perception around the age of 10 years

Language was observed to be one of the variables in the perception of the TFS and E cues in speech stimuli. Hence, studies done in the tonal and non-tonal languages revealed that fine structure cues dominate for tonal languages while envelope cues dominate for non-tonal languages (Smith et al., 2002; Xu & Pfingst, 2003). There are studies done in Indian languages such as in Malayalam (Indu 2016) and Kannada (Naveen 2017) to evaluation the speech perception cues from chimeric stimuli. The present study aims to influence of frequency bands, envelope and fine structure cues on perception of Tamil chimeric sentences in individuals with normal hearing.

1.1 Need for the study

Smith, Delgutte and Oxenham (2002), explored the importance of envelop cues and fine structure cues in individuals with normal hearing. It was reported that envelop cues were perceived by non-tonal language such as English and fine structure cues were majorly perceived in tonal languages.

Xu and Pfingst (2003) reported that for the perception of tonal languages such as Mandarin Chinese, the fine structure cues were important. Studies suggest that the temporal envelope plays an important role in identifying the non-tonal languages and temporal fine structure in identifying the tonal languages.

According to Indu (2016) the temporal fine structure plays an important role in identifying lower frequency bands and temporal envelope plays an important role in identifying higher frequency bands for identification of words in Malayalam. Naveen (2017) reported that the envelope cues were employed majorly than fine structure cues for identification of words and sentences in Kannada. However, most of the south Indian languages are non-tonal languages. Hence, there is a need to investigate whether the same trend follows in Tamil language also and to check if there is any difference in cues required for the identification of the chimeric sentences of Tamil language.

1.2 Aim

To investigate the influence of frequency bands, envelope and fine structure cues on perception of Tamil chimeric sentences in individuals with normal hearing.

1.3 Objective

- To study the influence of envelop on perception of Tamil chimeric sentence identification.
- To study the influence of fine structure on perception of Tamil chimeric sentence identification.
- To find out the number of frequency bands needed to clearly differentiate between envelop and fine structure in Tamil chimeric sentence.
- To compare identification of chimeric sentences across the various frequency bands.

1.4 Hypothesis

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

- There are no significant effect of envelope on chimeric word and chimeric sentence identification in Tamil language.
- There are no significant effect of fine structure on chimeric word and chimeric sentence identification in Tamil language.

- There is no significant effect of number of frequency bands for the identification of envelope and fine structure cues.
- There is no significant effect of identification of chimeric sentences across the frequency bands.

Chapter 2

Review of literature

When a sound is received by the cochlea, it functions like a frequency analyzer in the auditory system, where the frequency content of the signal is mapped into a pattern of excitation on the Basilar Membrane (Chen, Clark, & Jones, 2003). The excitation pattern of the acoustic stimulus is cored in the cochlea as spectral place information (Dallos & Fay, 1996). The spectral information is crucial in language recognition because phonetic features are characterized by their frequency spectrum. Basilar membrane functions like a bank of band pass filter which has the property of frequency selectivity, with every filter corresponds to a particular place on the basilar membrane (Russel et al., 1986). The output signal from these band pass filters carries important temporal information as a slowly varying envelope modulation superimposed on rapidly oscillating fine structure (TFS). This temporal information is relayed to the sensory nerve (Smith et al., 2002; Xu & Pfingst, 2003; Zeng et al., 2004).

2.1 Envelope versus temporal fine structure cues for speech perception

The rate of change in auditory nerve firing is associated with envelope and the rate of firing is associated with fine structure (Young & Sachs, 1979; Young, 2007). The relative change in the magnitude of envelope across channels relays information for the auditory system to identify the signal spectral shape and its slow short-term spectral changes. The TFS provides cues about the central frequency of the sound and about its short-term spectrum.

It is usually assumed that TFS are not perceived as an important cue due to poorer face locking property at frequencies above 4 - 5 kHz. Speech identification requires envelope information in silent situation even when provided in as few as four frequency bands (Flanagan, 1980; Shannon et al., 1995; Smith et al., 2002). But in the presence of background noise more frequency bands are required for the ENV speech identification (Qin & Oxenham, 2005; Stone & Moore, 2003). As the results shown, ENV cues are enough to provide intelligibility in silent, but slightly degraded in the presence of fluctuating noise. This is the reason that current cochlear implants provide ENV information over a small number (8 to 16) of electrodes (Wilson et al, 1991). On the other hand, TFS or temporal fine structure is associated with perception of pitch and sound localization (Nelson et al., 2003; Qin & Oxenham, 2003, 2006; Smith et al., 2002; Fullgrabe et al., 2006).

There are several studies which have been carried out in identifying the predominance of ENV vs. TFS cues on the perception of speech. A study by Fu, Zeng, Shannon, Soli, and Shannon., (2006); Pfingst, Arbor, and Pfingst., (2003); Smith et al., (2002) in which the comparative role of speech envelope (E) and temporal fine structure (TFS) cues on speech identification was assessed in which one cue is varied while the other was kept intact this was accomplished by the vocoders. This vocoded speech is generated by extracting the two cues from the speech signal and the envelope cue is set to modulate the tone or noise by separating it across frequency bands and the importance of this envelope cues was studied.

However, there are studies examined the potential contribution of TFS cue also. Xu and Zheng (2007) assessed the comparative importance of spectral and temporal cues for phoneme recognition, in which the spectral information was altered by changing the channels in the vocoder processing, however, the temporal cues were altered by changing the cutoff frequency of the envelope (E) using the low pass filter. It was found that there is a tradeoff between the spectral and temporal cues in identification of vowel and consonant which is because of enhancement of anyone cue reduces the other cue perception.

Nie Barco and Zeng (2006), reported on normal hearing individual and individuals with hearing impairment on identification of predominant cue for speech perception for that the spectral and temporal cues. The cues were altered by varying the number of channels and pulse rate, which revealed that the TFS cues were efficiently used by the normal hearing individual when compared with the hearing impaired. Supporting this findings, others (Hopkins & Moore, 2007; Hopkins & Moore 2009; Lorenzi Gilbert Carn Garnier & Moore 2006; Moore & Sęk 2009; Moore, Glasberg & Hopkins, 2006) have also reported that it is due to the impaired ability in individuals with hearing impairment on their phase locking ability, which in turn reduced their ability to decode the fine structure information. Lastly, due to the broad auditory filters will also be a substantial evidence to portrait the poor performance on understanding the fast changing TFS information in hearing impaired individual (Moore & Glasberg, 1987; Stone, Fullgrabe & Moore, 2008).

In accordance to the earlier researchers, a study by Hopkins and Moore (2007, 2009) on individuals with normal hearing and hearing impairment where the benefit of TFS cue was assessed using a sentence recognition task in which the threshold was obtained i.e., sentence recognition threshold (SRT), is the lowest hearing level in which an individual can identify 50% of the speech material. The researchers had quantified the importance of the TFS cue by altering the number of frequency bands containing the TFS information on a tone or noise vocoded stimuli. To examine the known fact that the hearing impaired individual had poor ability to use the TFS cue at high frequency in this study the researchers removed the TFS cues across the low, mid and high-frequency range and found that the hearing impaired individual had poor ability to use TFS at the mid and high-frequency range.

Hopkins and Moore, (2009) measured the sentence recognition threshold (SRT) in individuals with normal hearing while varying the TFS information present in the stimuli by deleting it from all bands above a cutoff frequency. It was found that the SRT significantly becomes poorer as the value of the cutoff channel increased, which suggests that TFS has importance in understanding speech in fluctuating background noise.

Gnansia, Péan, Meyer & Lorenzi, (2009) studied the effects of spectral smearing and degradation of TFS cues on masking release. Stimuli were processed using a spectral smearing algorithm or a tone vocoder technique. The fundamental frequency information was more degraded by the vocoder than the spectral smearing algorithm. Masking release was reduced more with the tone vocoder than spectral smearing. So, both frequency selectivity and TFS cues are essential for the ability to listen in the dips.

Importance of ENV and TFS cues in reconstructing missing information in interrupted speech was studied Lorenzi et al., (2006). Stimuli were processed to have different amounts of ENV and TFS cues. Intelligibility significantly deteriorated after adding a silence gap. TFS cues have a significant part in reconstructing the broken sentences. The TFS is not sufficient alone, but when the individuals were trained with ENV cues the perception of interrupted speech increased.

Presence and absence of ENV cues in the stimulus may affect the perception of TFS. There is possible recovery of ENV cues by the human auditory filters from a correctly processed signal having only TFS cues. A narrow-band filter can recover the signal ENV from the fine- structure information (Voelcker, 1966). This is can happen in humans because of the sharp cochlear tuning (narrow filters), which facilitate the retrieval of the slow amplitude variations (ENV) from the TFS signal (Ghitza, 2001; Heinz & Swaminathan, 2009; Zeng et al., 2004). Gilbert et al., (2006) argued that recovery of ENV cues from TFS-only signals has minimal contribution to speech recognition when the vocoder has a bandwidth less than 4 ERBN. When using 16 frequency channels should be sufficient to prevent the use of recovered ENV cues. Heinz and Swaminathan, (2009), nevertheless, presented physiological evidence for the presence of recovered ENV in chinchilla Auditory Nerve response to the chimeric speech. It was computed that 'Neural cross-correlation coefficients' measures the similarity between ENV and TFS to quantify the similarity between ENV or TFS components in the spike train responses.

The last method proposed by Sheft et al., (2008) was to limit the bandwidth of the extracted TFS signal of the analysis filter bandwidth in order to degrade ENV reconstruction. The results of revealed that TFS stimuli, processed to reduce chances of intelligibility from recovered ENV cues, were still highly intelligible (50%– 80% correct consonant identification).

Indu (2016) assessed in individuals with normal hearing and investigated the perception of ENV versus TFS cues using Malayalam chimeric sentences through speech identification task across 8 frequency bands. Results revealed that fine structure cues are predominance at lesser frequency bands. As the number of frequency bands is increased, predominance of perception for envelope cues was increased and there was a reduced perception for temporal fine structure cues were observed.

Naveen (2017) investigated speech identification through Kannada words and sentences across 8 frequency bands in individuals with normal hearing aged from 18 to 30 years .Results revealed that for identification of words the predominance of TFS cues persist till 16 bands and for sentences envelope cues were employed majorly than fine structure cues.

These review of literature elaborates the various studies pertaining the perception of fine structure and envelop cues in individuals with normal hearing and hearing impairment across the tonal and non-languages. However, from these review it is evident that there is dearth of literature on perception of temporal cues in South Indian languages. Hence, this present was taken to assess the perception of envelop and fine structure cues on Indian Tamil language across frequency bands.

Chapter 3

Method

The present study aimed to determine the performance of normal hearing young adults aged 18 to 30 years on the identification of speech using temporal fine structure cues and temporal envelope cues in auditory chimeric Tamil sentences.

3.1 Participants

Participants of the study included 40 normal hearing adults, aged between 18 years to 30 years (Mean=23.5 years, and SD= ±2.69), who were native speakers of Tamil.

3.1.1 Inclusion Criteria:

- Air conduction pure tone hearing thresholds less than or equal to 15 dB HL in both ears at octave frequencies from 250 Hz to 8000 Hz and bone conduction thresholds less than or equal to 15 dB HL in both ears at octave frequencies from 250 Hz to 4000 Hz as measured from pure tone audiometry using modified Hughson-Westlake procedure (Carhart & Jerger, 1959).
- Normal middle ear functioning as indicated by 'A' type tympanogram (Margolis & Heller, 1987).
- Ipsi-lateral and contralateral acoustic reflex thresholds within 100 dB HL at 0.5 kHz, 1 kHz and 2 kHz.
- Uncomfortable level for speech greater than or equal to 100 dBHL in both ears
- Presence of transient oto-acoustic Emissions 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 Tamil

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

3.2 Instrumentation

- A calibrated 'clinical audiometer' (GSI 61) with TDH 39 earphones enclosed in MX-41/AR supra-aural ear cushions to estimate the air-conduction thresholds, SRT and SIS; and Radio Ear B-71 bone vibrator to estimate the bone conduction thresholds.
- A calibrated 'Grason-Stadler TympStar (version 2)' middle ear analyzer to evaluate the status of the middle ear.
- HP laptop, core i3 processor loaded with the following softwares: Hilbert transform using MATLAB software [MATLAB 7.12.0 (R2011a)].
- The audio output of the laptop was routed through a THD-39 head phone housed in MX-41AR supra aural cushions.
- Adobe Audition (version 3.0) software was used for the presentation of the stimulus
- PRAAT (version 6.0.39) software was used for recording the response of the subject.

3.3 Environment:

The testing was carried out in sound treated double room where the noise levels are within permissible limits (ANSI S3.1-1999).

3.4 Material

Sentences for preparing chimeric list was selected from "Sentence from Production of language training materials in major Indian languages, (Manjula et.al, 1990).

3.5 Procedure

The study was carried out in two phases:

3.5.1 Phase 1

Preparation of the test stimuli: This involved selection of sentences in Tamil and preparing auditory chimeric stimuli. The sentences were selected such that the total number of syllables in each sentence was limited to eight-nine syllables and each word in sentences was not more than three syllables. Total of eighty pairs of sentences were taken to prepare speech – chimera across eight frequency bands which includes one, four, six, thirteen, sixteen, twenty-eight, thirty-two, and sixty-four. So a total of 160 sentences were prepared. In which each band consists of 10 chimeric sentences.

3.5.2 Phase 2

Administration of the test stimuli: It involved administration of the prepared chimeric sentences across 8 frequency bands for the participants.

3.5.2.1 Phase 2.1: Preparation of Stimuli and Selection of Participants

The selected eighty pairs of sentences were processed using Hilbert transform to extract the temporal cues such as envelope and fine structure. Hilbert transform is mainly used to derive envelope function or instantaneous amplitude of a signal. It mainly represents a filter without affecting the gain (Yost & Fay, 2007).

Hilbert transform is computed in a few steps:

- First, calculate the Fourier transform of the given signal x(t).
- Second, reject the negative frequencies.
- Finally, calculate 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. Thus, Hilbert transform can be interpreted as a way to symbolize 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, these temporal cues were exchanged with each other in order to make speech auditory chimeric sentences. Likewise cues were exchanged between all sentences and 80 chimeric sentences are made.

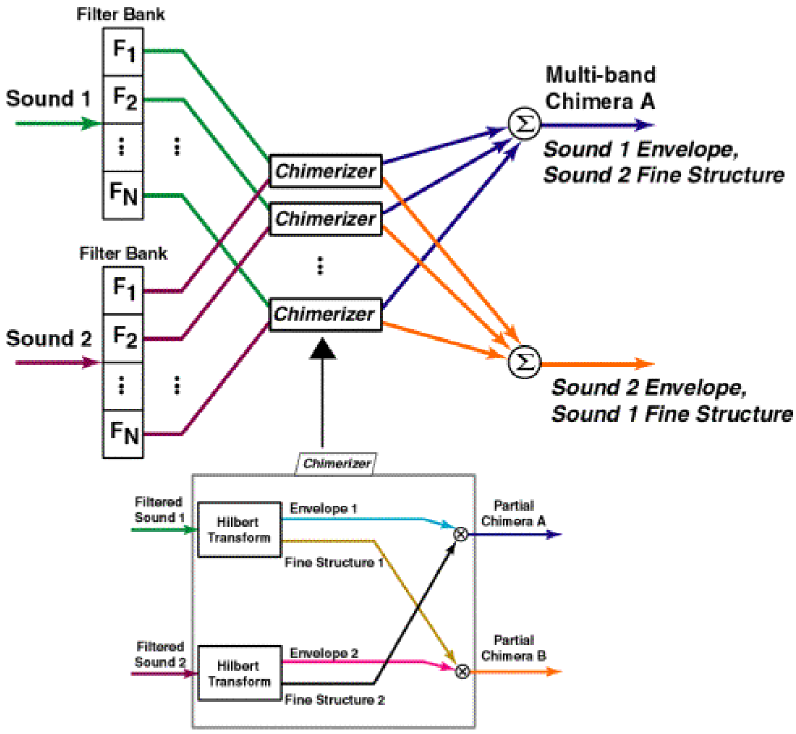

Figure 3.1: *Diagrammatic representation of the preparation of chimeric stimuli*

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

***3.5.2.2 Phase 2.2: Administration of Chimeric Stimuli*:**

All chimeric stimuli having frequency bands of 1, 4, 6, 13, 16, 28, 32 and 64 were given through the headphone TDH-39 at the most comfortable level. For each participants practice trial using three chimeric stimuli was given prior to testing. Instruction provided include 'Listen carefully to each word and repeat back the word that were identifiable'. Speech identification scores were considered based on the percentage of number of correct key words identified from each auditory chimeric sentences.

Chapter 4

Results

The present study aimed at determining the influence of frequency bands, envelope and fine structure cues on perception of Tamil chimeric sentences on individuals with normal hearing. The data was collected on 40 participants who were native speaker of Tamil language for assessing the speech identification for fine structure and envelope cues across 8 frequency bands (1, 4, 6, 13, 16, 28, 32 & 64). The collected data was tabulated and subjected to statistical analysis using SPSS software version 21.

Results of Shapiro-Wilk test showed non normal distribution across the participants. So, non-parametric tests were carried out for further statistical analysis.

The outcomes of the study are explained under the following:

1. Identification of chimeric sentences across frequency bands
2. Number of frequency bands needed to clearly differentiate between envelop and fine structure in chimeric sentences
3. Comparison of chimeric sentences identification across frequency bands

4.1 Identification of chimeric sentences across frequency bands:

The participants were presented with eight lists of chimeric sentences representing different frequency bands containing 10 chimeric sentences (4 key words in each). Chimeric sentences each correct identification of key words was awarded with 1 score.

The mean raw score and standard deviation scores of speech identification for chimeric sentences across different frequency bands with respect to envelope cues or fine structure cues were calculated using the descriptive statistical analysis as indicated in table 4.1

Table 4.1 Overall Raw Mean, Median and Standard Deviation (SD) of Chimeric Sentences across Different Frequency Bands for Perception of Envelope and Fine Structure Cues

Stimulus (Bands)	Envelope (ENV)			Temporal Fine structure (TFS)		
	Mean	**SD**	**Median**	**Mean**	**SD**	**Median**
1	0	0	0	0.16	0.16	0.2
4	0	0	0	0.37	0.22	0.4
6	0.26	0.27	0.3	0.20	0.26	0
8	1	0.34	0.9	0	0	0
16	3.91	0.13	4	0	0	0
24	3.98	0.01	4	0	0	0
32	5	0	5	0	0	0
64	5	0	5	0	0	0

Note: ENV= Envelope, TFS = Temporal Fine Structure, 1-64 indicates a number of frequency bands.

The data of the above table 4.1 shows an improvement of chimeric sentence identification as the number of frequency band increases.

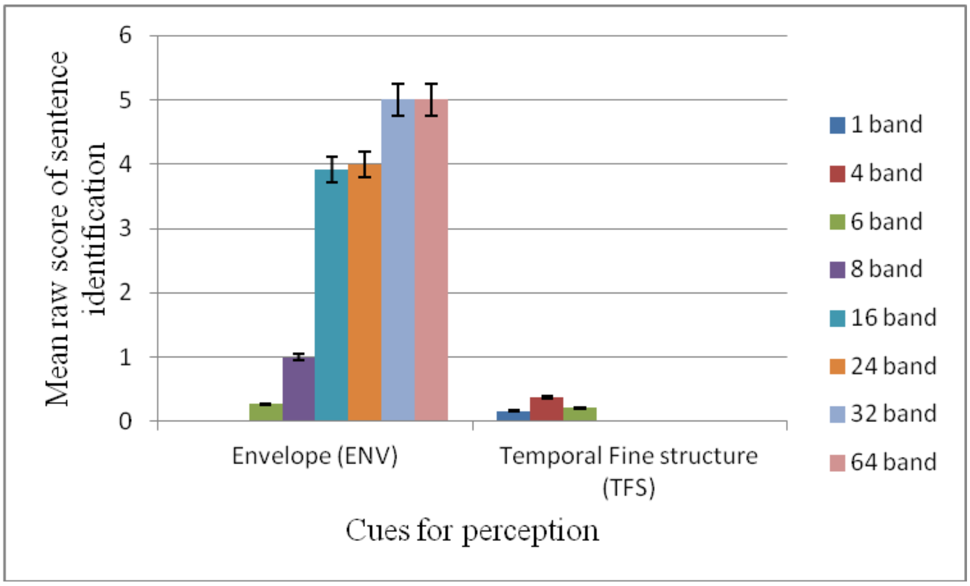

Figure 4.1: Raw mean score of chimeric sentence identification across bands and between cues

Above figure 4.1 shows mean score of chimeric sentence identification across the 8 frequency bands which show an improvement in sentence identification as frequency band increases from S1 to S24 and above that improvement stabilizes till S64.

4.2 Number of frequency bands needed to clearly differentiate between envelop and fine structure in chimeric sentences:

Participants were presented 80 chimeric sentences across 8 frequency bands (10 in each). All the sentences included 4 key words. Task was to identify the key words and repeat them. Results of the responses for participants are presented in table 4.2

Table 4.2: Representation of participant frequency (%) for identification of fine structure and envelope cues across frequency bands in chimeric sentences.

Frequency Bands	Fine Structure (%)	Envelope (%)
S 1	55	0
S 4	85	0
S 6	45	55
S 8	0	100
S 16	0	100
S 24	0	100
S 32	0	100
S 64	0	100

Note: S = Chimeric sentence list, 1- 64 indicates number of frequency bands

Above Table 4.2 results revealed that at lower frequency bands, identification of fine structure cues are prominent as the frequency band increases envelope cues dominates over fine structure cues in chimeric sentence identification.

Further Friedman test was administered to check if there is any difference on envelope cues across bands for chimeric sentences. The results showed a significant difference among bands in chimeric sentences as shown in table 4.3.

Table 4.3: Result of Friedman test for comparison of chimeric sentences across all frequency bands on envelope cues

Stimuli	**$\chi 2$**
Chimeric sentences	20.52*

*Note: * indicates p < 0.01*

In the table 4.3 it is to be observed that there was a significant difference observed across all frequency bands on envelope cues.

4.3 Comparison of chimeric sentences identification across frequency bands:

Since the Friedman test revealed significant differences across bands, Wilcoxon signed rank test was done to find out pairwise comparison across different bands of chimeric sentences and results are shown in Table 4.4

Table 4.4: Result of Wilcoxon signed rank test for comparison across frequency bands within envelope cue on chimeric sentence identification

	1 ENV	4 ENV	6 ENV	8 ENV	16 ENV	24 ENV	32 ENV	64 ENV
1 ENV								
4 ENV								
6 ENV				5.44**	5.53**	5.56**	5.57**	5.57**
8 ENV					5.51**	5.51**	5.51**	5.51**
16 ENV						3.22*	5.72**	5.72**
24 ENV							6.25**	6.25**
32 ENV								
64 ENV								

*Note: * indicates $p < 0.01$, ENV = envelope*

Results showed a significant difference across all pairwise comparison. The comparison was carried out for the frequency bands 6 through 24 bands. Where, the perception of envelope cues starts to occur only from the 6 bands. However, for the scores at 32 and 64 bands since the ceiling effect was observed in all the participants statistically analysis was not carried for those bands. It was also observed that there was significant difference for all the pairs for which the statistical analysis was done.

Table 4.5: Result of Wilcoxon signed rank test for comparison across frequency bands within TFS cue on chimeric sentence identification

	1 TFS	4 TFS	6 TFS
1 TFS		-4.37**	-1.06
4 TFS			-2.85*
6 TFS			

*Note: * indicates $p < 0.01$, TFS = Temporal fine structure*

The Table 4.5 revealed that the pairwise comparison between TFS cue at 1 through 6 bands showed significant difference between 4 and 6 bands. However 6 and 1 bands comparison revealed no significant difference.

Chapter 5

Discussion

In general, any speech stimuli consist of two cues in it, which are majorly employed by two temporal cues: ENV and TFS cues. Of which, the ENV cues are slow varying in nature and act as a amplitude modulators whereas the TFS cues are fast or rapidly changing to time (Moore & Sek, 2009; Rosen, 1992). These cues can be studied distinctly by mathematical factoring into two separate cues using different algorithms, one of which is the peak clipping and filtering (Licklider & Pollack, 1948). In this technique, the peaks were clipped and the signals were subjected to low pass or high pass filtering and then the signals are made to vocode with a tone or noise. The major disadvantage of this method is that it provides differentiation between the cues for perception however it is not; instead it creates more of distortion. Hence, another technique came in existence for extraction of different cues called the Hilbert transform (Bracewell & Bracewell, 1986) where it uses the mathematical calculation and FFT to extract the two features from a speech stimuli separately and a speech to speech chimaeras are prepared across frequency bands. However, earlier studies on individuals with normal hearing across different languages like Malayalam (Indu, 2016) and Mandarin Chinese language (Xu et al., 2005) have revealed the predominance of TFS cue than ENV cue on speech perception. Naveen (2017) on the Kannada language with the earlier study as a base on ruling out the relative importance across cues found ENV to be perceived better with perception predominance start from 4 frequency bands which is similar to that of study on the English language.

However, there is scarce of literature in identifying predominance of temporal cues in Tamil language. Hence, the current study focuses on establishing the predominance between the two temporal cues and also to explore the number of bands required to clearly differentiate between the cues. The results revealed a predominance of TFS cues at low frequency bands from 1 through 6 bands and E cues from 6 through 64 bands. However, the significance was observed only till 24 bands whereas, in 32 and 64 bands, the significance was not computed due to ceiling in the scores of sentence identification.

The study results are in support with the earlier study carried out in Malayalam language, where the authors observed low frequency bands predominated by TFS cue and the high frequency bands predominated by envelope cue in identifying sentences Indu (2016). In Malayalam language, the ceiling of the chimeric sentence identification score at the high frequency bands was not observed. But in contrast, the ceiling was observed in Kannada language at high frequency bands with no identification of chimeras for TFS cues in both sentences and words and even at low frequency bands with major predominance observed only on the ENV cues Naveen (2017).

Similar results were observed in studies conducted by Smith et al, (2002), Xu and Pfingst (2003) in non-tonal English language where it is concluded the predominance of ENV cues on speech perception from 4 frequency bands with static increment in the scores as with the increase in number of frequency bands. This supports that Tamil language also incorporates more of non-tonal quality in speech sounds with subtle existence of tonality component. Due to this tonality, there is predominance of TFS at low frequency bands as supported by Xu et al., (2005) on Tonal Mandarin Chinese language where speech perception was entirely predominated by TFS cue from 1 - 32 bands with the gradual increase in the performance as of with increase in the number of frequency bands.

Chapter 6

Summary and Conclusion

To summarize the present study, for perception of tonal language, fine structure cue plays a major role whereas for non-tonal language, envelope cues are crucial. However, in Indian context, most of the languages are non-tonal in nature and hence studies were conducted in Malayalam and Kannada language. With these two studies as a base, the results cannot be generalized to other languages as India being a diverse country, there is variation in context and regional variation in the nature of language spoken. Hence, there is a need to study each of the Indian languages separately. Therefore, the aim of the present study was to investigate predominance between the cues and number of bands required to clearly differentiate between the cues in Tamil language on individuals with normal hearing. The following are the objectives of the study: 1) To investigate the influence of envelope and fine structure cues on chimeric sentence identification 2) To explore the number of frequency bands required to differentiate the cues for envelope and fine structure cues on chimeric sentences. The study began with the assumption that envelope and fine structure cues do not have any effect on sentence identification in Tamil language. The study was carried out in two phases: Phase 1 included the preparation of chimeric stimuli and phase 2 included the presentation of stimuli and administration of chimeric sentence identification task. Descriptive statistical analysis was carried out on SPSS software (version 21).

The results revealed that fine structure cues are employed majorly at lower frequency bands and as the number of frequency bands increased, envelope cue solely found to have influence on speech perception. In other words, speech perception was predominated by TFS cue at low frequency bands and envelope cue at high frequency bands.

Clinical implications

- The present study's results reveal that envelope cues are important for the perception of Tamil language.
- The current findings of the study highlights the need to include methods such as encoding envelope in the form of frequency modulation, or a race to spike algorithm, or using coherent demodulation in the single band encoder which preserves both envelope and fine structure.
- For hearing aids the strategies that can be adapted includes spatio-temporal pattern correlation or Neuro-compensator algorithm to provide envelope cues for better perception of Tamil language.
- The current study highlights the need to focus on envelope cues in intervention of individuals with cochlear lesion.

Future Direction:

- To gain in depth knowledge regarding the same, a detailed study across different age groups and different languages to be carried out.

- The study is carried out on individuals with normal hearing. However, this study can be extended with hearing aid processed stimuli on the same population.
- More study is required to generalize the perception on individuals with hearing impairment

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