Rhythm Perception with Fine Structure Cues: A Simulated Study

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Abstract

The present study aimed at investigating the effect of adding fine structure cues in rhythm perception. All the speech coding strategies used with cochlear implants extract the envelope of the signal and code the information while missing out information on the fine structure cues. In this study, the fine structure cues were provided along with the envelope and the rhythm perception enhancement was studied. A group of 30 individuals with hearing within normal limits served as subjects for the study. The stimulus consisted of thirty rhymes which were modified by the MATLAB 6.5 software into envelope only (AM) and envelope + fine structure (AM+FM) conditions with 4, 8, 12 channels respectively. Significant improvement in the rhythm perception was seen with the addition of fine structure cues. This study focuses on the importance of adding fine structure cues in the cochlear implant processing strategy to enhance the performance of cochlear implant users in both speech and music perception

Keywords: *Envelope cues, Fine structure cues, Cochlear implants, FAME strategy, Rhythm perception.*

Introduction

Cochlear implants (CI) are devices that have been successful in restoring hearing to profoundly deaf patients through electrical stimulation of the auditory nerve with fine electrodes inserted into the scala tympani of the cochlea. The performance of cochlear implants depends on the speech processor's ability to faithfully decompose speech signals into a number of channels of narrow-band electrical signals that is used to activate the spiral ganglion cells of the auditory nerve. The number of electrodes in modern cochlear implant devices may be different from the number of channels in the speech processor, and may vary from 12 to 22 or more depending on the strategy used or with the monopolar or bipolar stimulation used. The configuration and placement of the electrodes are of importance to the overall performance of these devices.

Components of music perception:

Every person is immersed in an environment full of sound and being able to understand speech is not the only function of hearing. For most people, listening to music is also a significant and enjoyable experience. Natural speech carries abundant acoustic cues in both spectral and temporal domains (Smith, Delgutte and Oxenham, 2002), while music is very complex and wide ranging. Pitch conveys melody and is strongly related to the spectral content of the sound. For accurate musical perception, all three of these characteristics must be transmitted. Rhythm, pitch, timbre and melody identification requires good functioning of highly specific patterns of discrimination.

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Rhythm: temporal patterns in musical sounds along with overall variations in loudness are perceived as the rhythm.

Melody: the ability to recognize melody depends on highly variable factors, such as individual's musical training, the socio-cultural experience, memory of the tune and situational contexts. The ability to perceive accurately the fundamental features of musical sounds, such as pitch and temporal patterns is a pre-requisite for melody recognition.

Timbre: the principal properties of the frequency spectrum and the amplitude envelope of sounds, including changes in those attributes over time and frequency are also relevant (Fragoulis, 1999).

Music perception in Cochlear implants

Investigators have shown that trends in the patterns of correlation between speech and music perception suggests that particular structural elements of music are differently accessible to cochlear implant users (Gfeller and Lansing, 1997; McDermott and Mckay, 1997). Pitch cues can be elicited using two independent mechanisms in cochlear implants, namely place pitch and temporal pitch cues (Tong, Clark and Blamey, 1982; Shannon, 1983; Mckay, McDermott and Clark, 1996). Temporal pitch cues arise when the repetition rate of stimulation on one channel changes. The temporal pitch sensation rises with increasing rate up to 300 Hz but saturates at higher rates (Shannon, 1983). Place pitch cues arise when the site of stimulation is changed while keeping the stimulation rate constant, with more basal stimulation eliciting higher pitches. It has been shown that both temporal and place pitch cues enable CI recipients to some degree perceive Fo differences of synthetic harmonic sounds with currently used sound processors (Geurts and Wouters, 2001), and in normal hearing subjects with acoustic models of CI processors (Green et al., 2004). Rhythm perception and melody perception was observed to be poorer than normal hearing counter parts due to inadequate cues provided through the cochlear implant (Gfeller and Lansing, 1991).

Music perception in CI subjects was poor compared to normal hearing subjects (Leal, 2003; Gfeller and Lansing, 1991). Pijl (1997) showed that at least part of the limited pitch performance of the CI subjects was due to ineffective sound processing as CI subjects were able to estimate musical intervals more accurately for synthetic stimuli (pulse trains) than for real musical sounds. Part of this limited Fo discrimination ability in CI recipients using their speech processors may be due to the limited transmission of the fine temporal information in current speech processors, since most current speech processors only extract the slowly varying envelope and use this to modulate a constant rate pulse (Smith, Delgutte and Oxenham, 2002).

The temporal envelope consists of frequency information in the 2-50 Hz range; periodicity consists of frequency information in the 50-500 Hz range and the fine structure consists of frequency information in the 600-10,000 Hz (Rosen, 1992).

It is commonly believed that envelope cues are represented in the auditory system as fluctuations in the short-term rate of firing in auditory neurons, while temporal fine structure (FM) is represented by the synchronization of nerve spikes to a specific phase of the carrier (phase locking) (Shannon, Zeng, Kamath, Wygonski and Ekelid,1995).

Current signal processing for cochlear implants allow adequate speech perception in quiet environments for most users. However, their speech recognition performance in noise and music perception is severely limited. Typically, each electrode receives an amplitude modulated pulse train representing the narrow band temporal envelope of a sound from a particular frequency band. Amplitude modulations from low frequencies are delivered to the apical electrodes and amplitude modulations from high frequencies are delivered to the basal electrodes. Though amplitude modulations are sufficient to support sentence recognition in quiet (Shannon, 1995), it is not sufficient for speech recognition in noise and music perception (Dorman, Loizou and Tu, 1998; Freisen, Shannon, Baskent and Wang, 2001). The pitch of the voice can be conveyed by the temporal envelope; however this cue provides a relatively weak representation of pitch especially for the high frequencies. This indicates that pitch information is not effectively coded by the envelope modulations and hence not sufficient for rhythm perception (Green and Rosen, 2004).

Need for the study:

The speech processing strategy in most modern cochlear implants extracts and encodes only amplitude modulation in a limited number of frequency bands and hence the place pitch coding is impaired. To overcome the inherent limitations of temporal pitch coding in cochlear implants, techniques may be needed to provide perceptual information about the “fine structure” of the acoustic signals. The fine structure contains rapidly varying components of sounds that are not present in the envelope coding strategies that are being used. Amplitude modulations alone do not provide good rhythm perception as described above; hence it is proposed to study the importance of adding fine structure cues in rhythm perception. .

In addition, investigators demonstrate that number of channels also affects music (rhythm) perception. Here, we propose to understand how a novel speech processing strategy that encodes frequency modulations with varying number of channels improves cochlear implant performance in rhythm perception.

Aim of the study:

The study aims to understand the

1) Effect of number of channels on rhythm perception with envelope cues (amplitude modulation).
2) Effect of number of channels on rhythm perception with fine structure and envelope (amplitude and frequency modulation) cues.

3) To compare rhythm perception with the fine structure and envelope (AM + FM) condition and envelope only (AM) condition across different channels.

Method

A. Subjects:

The study included of 30 subjects with normal hearing in the age range of 18-25yrs (15 females and 15 males with the mean age of 21.5years). Pure tone audiometry thresholds at all frequencies were within 20 dBHL. No indication of middle ear pathology as shown by tympanometry and presence of acoustic reflexes at 500 Hz and 1000 Hz.

B. Instrumentation:

- A calibrated dual channel clinical audiometer and a calibrated Immittance meter were used to recruit subjects.
- A dual channel clinical audiometer was used for the testing.
- The stimulus generated using MATLAB 6.5 software was played using an Intel Pentium processor computer.

All the testing, both for selecting subjects and for experimental purposes were conducted in an air conditioned, acoustically treated double room set-up. The ambient noise levels inside the test room were within the permissible limits (re: ANSI S3.1 1991, as cited in Wilber 1994).

C. Stimulus and signal processing:

The stimulus consists of thirty nursery rhymes (30 rhymes; 5 rhymes in each of the six conditions). The simulation was done using MATLAB 6.5 software. The stimulus contains cues in the frequency range (100 Hz -10,000 Hz). The stimulus was separated into its envelope (AM) and fine structure (FM) using FAME (frequency and amplitude modulation encoder) software. Frequency modulation (FM) was used to code the instantaneous frequency, or temporal fine structure of the speech waveform, while the envelope (AM) coded the instantaneous amplitude of the signal.

The stimulus was filtered into 4, 8, 12 narrow bands with third order Butterworth filters respectively. Each of the narrow bands was then subjected to full-wave rectification to obtain the slowly varying envelope followed by a low pass cut off filter at 500 Hz (first order Butterworth filter) to control the amplitude modulation rate, to form the AM component of the synthesized signal. The envelope thus extracted was then modulated with sinusoids of 100 – 10,000 Hz frequency range to produce the AM signal. The fine structure (FM) was extracted using FAME software. This was followed by low pass filtering (500 Hz) to limit the FM depth and rate to relatively slowly varying components that can be perceived by the cochlear implant users, an optimum of 500 Hz bandwidth and 400Hz rate was used (Stickney, Nie and Zeng, 2005). The processed signal was then band pass filtered to remove any frequency components that fall outside the analysis filters bandwidth.

Finally, the band passed signals were summed to form the synthesized signals that contain AM and FM components. The slowly varying envelope modulated with the sinusoids of 100 Hz-10,000 Hz formed the AM component of the signal.

D. Procedure:

The stimulus was presented in a sound treated room in the free field condition at 40 dBSL. The subjects were asked to tap the rhythm of the rhymes heard (Schutz and Kerber, 1993). All the thirty rhymes were presented to the thirty subjects randomly in the six conditions. The conditions include

Amplitude modulated stimulus with 4 channels,

A. Amplitude modulated stimulus with 8 channels,
B. Amplitude modulated stimulus with 12 channels,
C. Amplitude modulated and Frequency modulated stimulus with 4 channels,
D. Amplitude modulated and Frequency modulated stimulus with 8 channels,
E. Amplitude modulated and Frequency modulated stimulus with 12 channels.

The stimulus was presented and the participants were asked to tap out the rhythm heard. The rhythm pattern tapped was scored on a sheet for all the thirty (single foot) rhymes. This pattern was then compared with a model created from the tap pattern of three speech language pathologists who were well versed in music. Each correct tap was scored one and the incorrect tap was scored zero.

Results and Discussion

The present study aimed at investigating the effect of adding fine structure cues in rhythm perception. All the speech coding strategies used with cochlear implants extract the envelope of the signal and code the information while missing out information on the fine structure cues. In this study, the fine structure cues were provided along with the envelope and the rhythm perception enhancement was studied. A group of 30 individuals with hearing within normal limits served as subjects for the study. The stimulus consisted of thirty rhymes which were modified by the MATLAB 6.5 software into envelope only (AM) and envelope + fine structure (AM+FM) conditions with 4, 8, 12 channels respectively.

The following effects were analyzed using the repeated measure ANOVA with age as the independent variable

a) The effect of using only envelope (AM) cues in rhythm perception with respect to 4, 8,12 channels.

b) The effect of using fine structure (FM) cues along with envelope (AM) cues in rhythm perception with respect to 4, 8,12 channels.

c) Paired t-test was done to compare the effects of envelope only and envelope and fine structure cues with respect to 4, 8,12 channels.

The results are as follows:

(a) Effect of only envelope cues on rhythm perception with 4, 8, 12 channels:

A repeated measure ANOVA was performed with the number of channels and envelope cues (AM). There was a main effect of the number of channels. As expected the 12 channel condition produced higher scores than 8 channel condition, however there was no significant difference between 4 and 8 channels.

*AM represents envelope only condition.

*AMFM represents the condition where both envelope and fine structure cues are presented.

Figure 1 comparison of percentage correct scores across gender and 4,8,12 channels in AM and AM+FM condition.

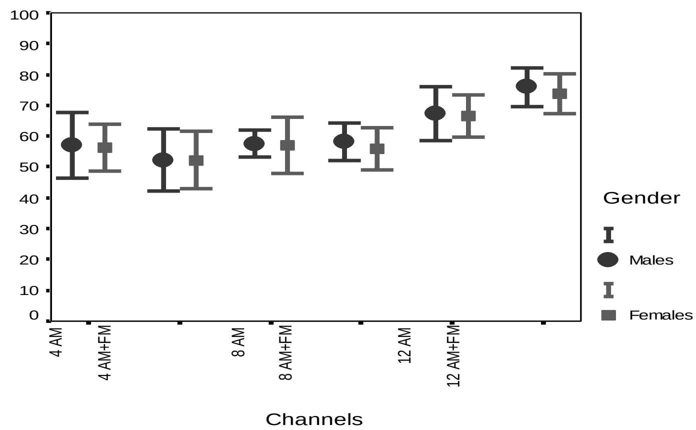

Figure 1: Depicts the mean and the standard deviation as error bars for different channels across gender. From this figure it is evident that there is significant difference between the channels (4, 8, 12 channels) in the envelope only condition.

The statistical analysis shows that there is a significant difference between 8 and 12 channels when only amplitude cues are provided, but there is no significant difference between 4 and 8 channels. The absence of significant difference between 4 and 8 channels could be due to the large standard deviation as shown in table-1. This is in consonance with the earlier studies (Freisen, 2001; Stickney, 2006) which showed that increase in number of channels improves the speech identification scores in quiet and in the presence of noise in cochlear implant users. Leal et al. (2003) demonstrated a significant correlation between speech perception in the presence of noise and rhythm identification and discrimination.

Table 1: Pair wise comparison across channels (4, 8, 12 channels) in the AM (envelope) condition.

(I) AM	*(J) AM*	*Mean difference (I-J)*	*Sig.*
1	2	-.633	1.000
	3	-10.290	.079
2	1	.633	1.000
	3	-9.657	.029*
3	1	10.290	.079
	2	9.657	.029*

* The mean difference is significant at the .05 level.

In addition, Nie, et al. (2006) demonstrated a significant improvement in all speech tests with increase in number of stimulating electrodes from 4 to 12. The improvement in the scores was more significant in the quiet than in the presence of noise.

Brill et al. (1997) and Fishman, et al. (1997) demonstrated that 4-6 channels are adequate to support high levels of speech reception in quiet , they also report that further increase in number of channels do not produce an increase in speech test scores. This is true for speech in quiet, but doesn't hold good for rhythm perception, as a significant improvement in scores is seen with increase in number of channels. This improvement in the scores with increase in number of channels can be attributed to the increased spectral information provided through the channels.

In addition, Freisen, et al. (2001) demonstrated that though the number of channels was increased CI users weren't able to utilize the spectral information provided by the additional channels. The reason for this limitation was quoted as the electrode interactions and possible tonotopic shifts and warping in the frequency to place mapping of spectral information. No improvement was observed in speech recognition as the number of channels was increased from 7 to 20 channels for vowel and consonant recognition and increased from 10 to 20 channels for sentence recognition. However in this study, the effect of number of channels can be attributed to the normal physiological system of the subjects due to which they are able to make use of the fine spectral and temporal cues unlike the compromised physiological system in cochlear implantees (Souza and Boike, 2006).

Gfeller and Lansing (1991) examined the performance of 18 adult cochlear implant users on rhythm perception with the "primary measures of music audition" (PMMA). The speech coding strategies used were SPEAK and F0 F1 F2 and the mean score for both schemes on the PMMA rhythm subtest was approximately 84% correct which is very close to the average scores obtained by a control group of 35 subjects with normal hearing (Gfeller, et al., 1997).

However, Leal et al. (2003) assessed rhythm perception by 29 recipients of the nucleus 24 electrode device. Twenty subjects used ACE while nine of them used SPEAK strategy. Rhythm discrimination and identification tasks were used. 24 of the 29 subjects obtained 75%-90% scores in the rhythm discrimination test while only 12 subjects obtained good scores in rhythm identification.

The statistical analysis also showed that there was no significant difference between gender and no significant interaction between the number of channels and gender. It is evident from the above studies, that rhythm perception is average in cochlear implant users and addition of fine structure cues could result in better rhythm perception due to the additional spectral and temporal cues available.

(b) Effect of number of channels (4, 8, 12 channels) on rhythm perception with envelope and fine structure cues:

Repeated measure ANOVA was performed with the number of channels and envelope + fine structure cues (AM+FM) conditions. There was a main effect of the number of channels. As expected the 12 channel condition produced higher scores than 8 channel condition, however there was no significant difference between 4 and 8 channels.

Table: 2 Pair-wise comparison across channels (4, 8, 12 channels) in the AM+FM (envelope + fine structure) cues condition.

(I) AMFM	*(J) AMFM*	*Mean Difference (I-J)*	*Sig.*
1	2	-4.867	.223
	3	-22.653	.000*
2	1	4.867	.223
	3	-17.787	.000*
3	1	22.653	.000*
	2	17.787	.000*

* The mean difference is significant at the .05 level.

It is evident that there is significant improvement in the scores as the numbers of channels were increased from 4 to 12 and 8 to 12 channels. But no significant differences in scores were obtained between 4 and 8 channels. There was no significant interaction between the number of channels and gender and no significant effect of gender on the scores as expected.

Similar to the previous condition, increase in the number of bands and addition of fine structure (FM) cues resulted in improved performance in rhythm perception task.

Frequency modulations derived from the temporal fine structure is important to support speech recognition in noise and other critical functions such as speaker identification, music perception, tonal language perception and sound localization (Smith, Delgutte and Oxenham, 2002). Similarly it was stated that additional FM(fine structure) cues helps the listener to better segregate the envelope of the target signal and hence helps in improved performance (Nie, et al., 2005; Zeng, et al., 2005).

In addition, Nie, et al. (2005) demonstrated improved performance in speech tests with increase in number of channels and addition of fine structure (FM cues). This improvement was significant in the presence of noise condition and hence applies for rhythm perception. Significant correlation was obtained between speech in noise and rhythm perception (Leal et al., 2003).

The results of this study are in support with the above studies which conclude that increase in the number of channels with the fine structure cues (FM) results in improved overall performance. This improvement in performance can be attributed to the increased spectral and temporal resolution provided in the envelope and fine structure (AM+FM) condition.

(c) To compare the effect of envelope cues (AM) only and envelope along with fine structure cues (AMFM) across 4,8,12 channels.

To compare the effect of additional FM cues (AM + FM) in rhythm perception with 4, 8, 12 channels paired t-test was done.

Table: 3 paired Samples t Test across AM and AM+FM condition**.**

		T	Sig. (2-tailed)
Pair 1	P4AM – P4AMFM	1.333	.193
Pair 2	P8AM – P8AMFM	.077	.939
Pair 3	P12AM- P12AMFM	2.912	.007

The statistical analysis shows that there is a significant improvement in the 12 AM and 12 AM+FM condition, this can be attributed to the increased temporal and spectral information provided in this condition.

The results of this study are in accordance with the following studies:

Nie, Stickney and Zeng (2005) demonstrated that fine structure (FM) cues are crucial for improving cochlear implant performance under realistic conditions and also helps in music perception in normal hearing subjects. The subjects obtained large improvement in sentence recognition scores in the presence of noise. Speech perception in noise and rhythm perception are significantly correlated (Leal, et al., 2003). Hence, the improvements in the scores in this study are attributed to the better temporal and spectral representation of the signal.

Lan, Nie, Gao and Zeng (2004) demonstrated that the novel speech processing strategy with dynamic modulations of both frequency and amplitude is encouraging as it resulted in significant improvement in perception of Chinese tones, phrases and sentences. Experimental results reveal that tonal information in Chinese speech was encoded primarily in the fine details in the spectrum of the speech signal. It is inferred from this study that if the perception of tonal languages improves with the novel processing strategy, then rhythm perception which depends on the overall loudness variations of the signal will also be perceived better.

Stickney, Nie and Zeng (2005) demonstrated a significant improvement in the speech perception scores when fine structure (FM) cues were added to the envelope (AM) information especially in realistic listening environments. The addition of FM cues would provide information about pitch and formant transitions which will help in better speech and music perception, in turn rhythm perception.

Zeng, Nie, Liu, Stickney, et al. (2004) demonstrated that envelope cues are important for speech perception whereas the fine structure cues are critical for pitch perception which in turn enhances rhythm perception.

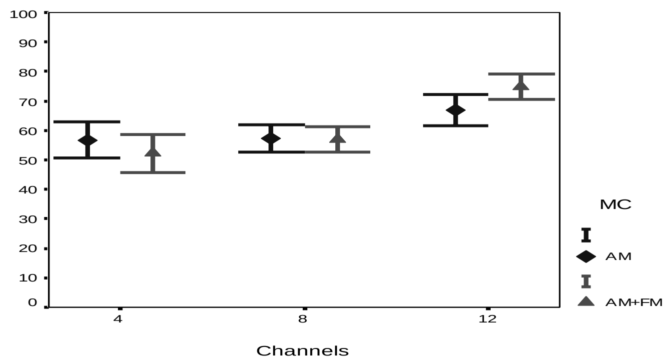

Figure 2: Comparisons of percentage correct scores across number of channels

To summarize, from the figure 2 it is evident that subjects showed improved performance with fine structure cues (AM+FM) and with increased number of channels. This increase in the scores can be attributed to the increased spectral and temporal resolution provided with 12 channels and the additional fine structure cues.

Conclusions

The present study aimed at investigating the effect of adding fine structure cues in rhythm perception. All the speech coding strategies used with cochlear implants extract the envelope of the signal and code the information while missing out information on the fine structure cues. In this study, the fine structure cues were provided along with the envelope and the rhythm perception enhancement was studied. A group of 30 individuals with hearing within normal limits served as subjects for the study. The stimulus consisted of thirty rhymes which were modified by the MATLAB 6.5 software into envelope only (AM) and envelope + fine structure (AM+FM) conditions with 4, 8, 12 channels respectively.

The investigation was carried out to address the following research goals:

- To determine effect of number of channels on rhythm perception with envelope cues (AM).
- To determine the effect of number of channels on rhythm perception with envelope and fine structure cues (AM+FM).
- To compare rhythm perception in the AM+FM condition and AM condition across different channels.

The results obtained are given below:

- In the first condition, i.e., rhythm perception with only envelope cues (AM) with 4, 8, 12 channels, significant improvement was seen between 8 and 12 channels, however no significant difference was measured between 4 and 8 channels. Hence it can be concluded that this improvement in scores with 12 channels could be due to the increased spectral information provided. However, the absence of improvement between 4 and 8 channels could be due to the large standard deviation obtained in this condition.

- In the second condition, i.e., rhythm perception with envelope and fine structure cues (AM+FM) with 4, 8, 12 channels, significant improvement was seen between 8 and 12 channels, however no significant difference was measured between 4 and 8 channels. This improvement in scores with 12 channels could be attributed to both the increased spectral information and temporal information provided by the fine structure cues. However, the absence of improvement between 4 and 8 channels could be due to the large standard deviation as mentioned.

- In the third condition, i.e., rhythm perception with envelope cues (AM) only and envelope + fine structure cues (AM+FM) with 4, 8, 12 channels, significant difference was seen between 12 AM and 12 AM+FM condition. However, no significant difference was seen between 4 AM and 4AM+FM condition, 8 AM and 8 AM+FM condition. Thus it can be concluded that significant difference between AM and AM+FM condition is seen only in the optimal condition, i.e., the condition with the maximum spectral and temporal cues (12 AM and 12 AM+FM condition).

This study focuses on the importance of adding fine structure cues in the cochlear implant processing strategy to enhance the performance of cochlear implant users in both speech and music perception. Further studies need to be done to understand the effect of fine structure cues on melody and timbre perception, which will provide in depth information about the music perception. Studies should also be replicated in cochlear implant users to understand if similar results are obtained in them, as many other factors determine the performance of cochlear implant users unlike a simulated study on subjects with normal hearing.

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