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ORIGINAL ARTICLE

Environmental Sound Perception with Amplitude and Frequency Modulations in Simulated Cochlear Implant

Varun G Rai, Attigodu Chandrashekara Ganesh

Beltone hearing aids Bangalore (VGR)
M.V. Shetty College of Speech and Hearing, Maladi Courts, Kavoor (ACG)

Objective: The present study investigated the effect of frequency modulation and amplitude modulation on perception of environmental sounds of different categories in the acoustic simulation of cochlear implant.

Materials and Methods: The participants were fifteen graduate students of age ranging from 19 to 26 years with normal hearing sensitivity. Five categories of environmental stimuli important in everyday life were used (nature, mechanical/alerting, vehicles human and animals). These sounds were processed with a Frequency-Amplitude-Modulation-Encoding strategy, implemented in Matlab. The stimulus presentation and response acquisition were controlled via 'DMDX' software.

Results: Two way repeated measure ANOVA showed a significant difference between frequency modulation plus amplitude modulation and amplitude modulation conditions. A significant difference was seen within-subjects for different categories and significant interaction was seen between conditions & category.

Conclusions: Good scores on frequency modulation plus amplitude modulation condition emphasis the importance of FM cues. Hence future speech processing strategies for cochlear implants to focus on implementing fine structure cue which may facilitate the identification of environmental sounds. The present method can be used in the evaluation of Cochear Implantees performance on perception of environmental sound which is an important component of post implant auditory rehabilitation.

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Introduction

The main goal of an audiologist should be to assess the whole communication performance which includes various skills like speech perception in quiet and noise, localization of sounds, listening effort and perception of nonlinguistic sounds like music, environmental sounds. Among them, the perception of environmental sounds is an important skill which is performed by all listeners. Listening to environmental sound is basic to human survival, and it is an important mechanism in the process of communication, which gives information about the patient's quality of life [1]. It helps to identify the source of the sound which helps in altering behavior based upon the sound producing objects in the environment. The environmental sound provides information like alertness, awareness about sources or the event in that environment[2]. It answers the questions where, how and what is going on the in the surroundings [3]. An environmental sound can be defined as a sound that is produced by a real event, and has a meaning due to the causal relationship with that event [4].

Even though auditory perception includes both speech and non speech sounds, the non speech sounds such as environmental sounds are always disregarded. Most of

Corresponding address:
Ganesh A.C
Dr M.V. Shetty College of Speech and Hearing,
Maladi Courts, Kavoor, 575015
Phone no: +919738405101
Email: gani0017@gmail.com

the studies in auditory perception focused on how speech is perceived while ignoring the non speech sounds. There are only few studies, which explain about the sound perception and processing in normals and hearing impaired individuals [5]. Cochlear Implants (CI) are one of the significant options for the rehabilitation of deaf or individuals with severe hearing impairment. Although early, the implants were developed with limited goals focused on the perception of elementary environmental sounds, later the multichannel CIs on focused better speech perception [6]. The processing strategies are designed as per these needs, and the perception of non-linguistic or environmental sounds is neglected so these sounds are processed under the strategies which are designed for the speech sound processing. As a result, there is a poor performance in environmental sound perception in such individuals. Studies have shown that the environmental sounds are confusing, or even in some cases unpleasant at first for many implantees [7].

Many studies carried out on the environmental sound perception in CI, and they have observed that CI recipients are poorer than normal hearing participants in environmental sound perception [8, 9]. Most of the CI devices rely on extracting and representing temporal cue and missing the fine structure cue [10]. Shafiro has shown that for the perception of environmental sound spectral as well as temporal cues have important contributions. The identification scores improved with the increase in spectral resolution without distorting temporal cues. He also suggested that environmental sound perception can be affected easily by the effect of temporal and spectral distortions [2]. Inverso and Limb assessed the open set & closed set perception of nonlinguistic sounds in CI users. In 22 postlingually deafened CI users, they assessed the speech and environmental sound perception. They observed only a moderate correlation between speech and nonlinguistic tests. Also they found that the environmental sounds are difficult to perceive [6]. So it is clear that the environmental sound perception is very difficult using only the temporal cues. Shafiro stated that for a higher spectral resolution, there was increased on identification of environmental sound. His prospect was that fine spectral and temporal information should be provided with spectral resolution greater than 32 channels is important for the identification of environmental sound [11]. Nie et al suggested that for the better performance of CI in realistic listening situation frequency modulation should be extracted and encoded [10]

The contributions of AM and FM on speech perception particularly in realistic listening condition has been thoroughly studied [10] and also the perception of environmental sound perception has been studied in normal and CI population [2, 6, 11]. However, the previous studies have carried out mainly using spectral shift or varying the number of channels but how this FM cue will contribute to the perception of nonlinguistic sounds in CI population have to be studied in detail. One of the other important factors to be considered is in India the numbers of cochlear implantees are increasing rapidly, yet there is no particular standardized test material developed for the evaluation of environmental sound perception in these populations.

In this study, vocoder is used to simulate CI processing using frequency amplitude modulation encoding (FAME) strategy. In the past, many studies have carried out using sine-wave vocoder and noise band vocoder to simulate normal hearing listeners [12]. The reason to use these vocoders is that, in CI there are so many variables that are difficult to control in actual cochlear implants like the insertion depth of the electrode array, the surviving cells in the spiral ganglion, the cause and duration of deafness. So these vocoders represent the actual signal processing that happens in the cochlear implant. Many studies with respect to speech perception have shown good correlation with the results of the actual implant study. So using FAME strategy how FM cues will contribute to the perception of nonlinguistic sounds has investigated in the present study.

Materials and Methods

During the all stages of the study, the current ethic standards were taken into account. Fifteen young normal-hearing adults (age range of 17 to 27 years, mean=22. 43 years) were recruited from the student population of the College of Speech & Hearing, Mangalore. All the participants have pure-tone thresholds less than 20 dB HL at all audiometric

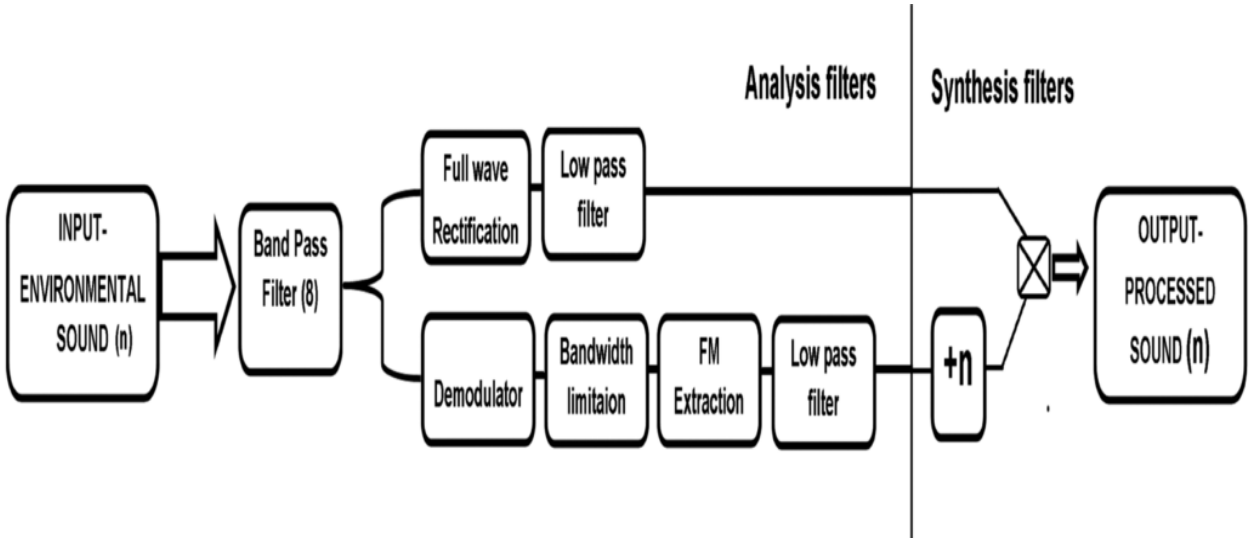

Figure 1. Block diagram of the Stimuli Signal processing

frequencies between 250 and 8000 Hz in both ears. Written informed consent was collected from the participants prior to their participation. A total of fifty environmental sounds that exists in the everyday life were selected for the present study. The sounds which were used in the present study are the collection of sounds that exists in the daily environment, and it's similar to the previous environmental sound perception studies [2, 6 9, 11]. All these sounds were downloaded from the royalty-free sound libraries (www. findsounds.com) and other sources which were used in the previous environmental sound studies. All environmental sounds were presented to 5 normal hearing participants for familiarity. The participants were asked to rate the familiarity of the sound using 3 point rating scale. Out of these 10 sounds in each category five most familiar sounds were selected. Twenty Fifty familiar environmental sounds under five categories were used for the present study. The lists of the sounds in each category are given in Table 1.

All sounds were processed with a Frequency-Amplitude-Modulation-Encoding (FAME) strategy, implemented in Matlab (Math works, Natick, MA). It's a strategy that's capable of extracting the slowly-varying amplitude and frequency modulations independently within a frequency band with the number of bands as an independent variable. Two experimental conditions were used in the present study in which processed stimuli to contain either the AM cue alone or both the AM and FM cues. The stimuli processing is similar to that of Nie et al study, which is represented in Figure 1.

Initially, all the environmental stimuli filtered into an 8 frequency analysis bands. The number of processing bands was selected based on the observation that an 8-band vocoder produces performance levels most similar to that of CI users [13]. The cut-off frequencies of the individual spectral bands were determined by first converting the lower and higher spectral limits in Hz into corresponding cochlear distances in mm, using the

Table 1. Representing the sounds presented in each category.

Animals	Mechanical/alerting	Nature	Vehicles	Human
Dog	Bell	Bee	Car	Clap
Cow	Door knocking	Crow	Helicopter	Brushing
Elephant	Telephone	Rain	Plane	Cough
Horse	Crackers	Rooster	Train	Cry
Sheep	School bell	Thunder	Ambulance	Laugh

Greenwood mapping function [14]. There are two pathways for each band pass filter, in that one if is for extraction of AM and another is for extraction for FM. The pathway of AM contains only slow varying temporal envelopes, which were extracted from the output of the analysis filters by full-wave rectification followed by a low-pass Butterworth filter. This low-pass cutoff filter controls the amplitude modulation rate. The pathway of FM extracts the slowly varying frequency modulation. Slowly varying temporal envelope and fast-varying fine structure extracted using Hilbert transform. In the FM extraction, the phase-orthogonal demodulators were used to demodulate and then followed by low pass filter which will control the parameters like the depth and rate of the FM. It is obtained by additionally frequency modulating each band centre frequency before amplitude modulation. The AM and the AM+FM processed sub bands were subjected to the same band pass filter and summation of these sub bands were carried out. For AM condition, the AM cutoff filter was set to 500 Hz, and the FM rate was set to 0.01 Hz, and the FM depth was set to 0.01 Hz. Whereas for AM+FM condition, the AM cutoff filter was set to 500 Hz and the FM rate was set to 400 Hz and the FM depth was set to 400 Hz. Each sound was presented 10 times each randomly for each subject and name of these 25 sounds were displayed on the computer screen in front of the subject simultaneously with presentation of sound. After listening to each stimulus subject was instructed to name the sound that most closely described the sound heard. The stimulus presentation and response acquisition were controlled via 'DMDX' software, which was installed on a personal computer using high fidelity Tech-Com Digital Sound stereo headphones (SSD-HP 202), presented at the most comfortable level ranging from 55-65dBSPL. The test was conducted in the sound treated rooms of the audiology department. The participant group was divided into two groups, i.e. One group had 8 subjects and 7 subjects randomly. To rule out the learning effect these modulated sounds are presented under both conditions after the gap of one week that is on the day1 Group1 is presented with AM condition and Group 2 is presented with AM+FM condition and after a gap of one week Group 1 is presented with AM+FM condition and Group 2 were presented with AM only condition. Identification accuracy scores were calculated and using comparisons between two conditions. SPSS 17 was used to analyze the data. The participants were made to hear the sound in a sound treated room.

Results

The overall identification score was better for the AM+FM condition (89.25%) compared to that of only AM condition (61.33%) which was consistent with previous studies where AM+FM condition produced good scores [10]. Two way repeated measure ANOVA showed a significant difference between AM & AM+FM conditions [$F(1.0, 74.0) = 169.86$, $p<0.001$]. Also Significant difference seen for within-subjects for different categories [$F(3.23, 239.67) = 17.21$, $p<0.001$] and Significant interaction between conditions & category [$F(3.068, 227.06) = 12.60$, $p<0.001$].

Performance scores were then analyzed by means of stimulus category (Figure 2 and Table 2) for both conditions. Overall, In the AM only condition the one-way ANOVA with Bonferroni corrections showed significant differences between the highest scoring category (mechanical) & the 4 lowest-scoring categories (animal, nature, vehicle, human) at $p<0.001$ & for AM + FM condition significant differences were seen between animal and the vehicle category at $p<0.001$.

Table 2. Identification Accuracy scores in AM and AM+FM condition in each category.

Categories	AM (%)	Standard deviation	FM (%)	Standard deviation
Animal	61.6	2.87	94.5	1.30
Mechanical	88.1	2.07	88.1	1.59
Natural	54.8	3.68	89.6	1.58
Vehicles	53.4	3.67	81.3	3.15
Human	48.6	4.09	92.2	1.92

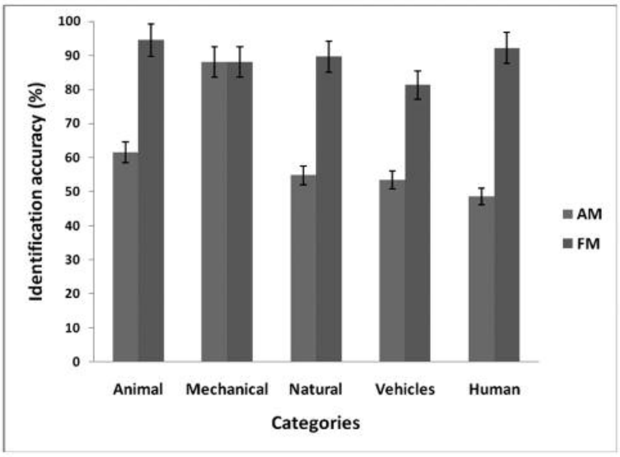

Figure 2. Accuracy scores in AM and AM+FM condition in each category

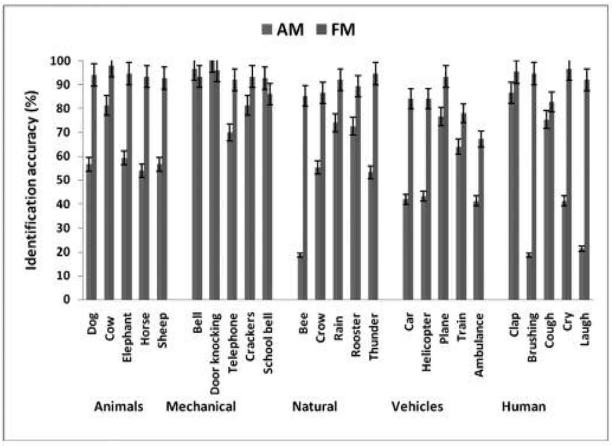

Figure 3. Comparison of each token score within the category in AM and AM+FM conditions.

Again performance was further analyzed with respect to individual sound tokens. Figure 4 shows how well or poorly participants identified specific sound tokens. In AM only condition best-recognized sounds were door knocking (100%) and door bell (100%) and least-recognized sounds were cough (13%). In AM+FM only condition best-recognized sounds were dog (100%), cry (100%) cow, door knocking (98%) and door bell (100%) and least-recognized sounds were train (44%). Overall in AM condition the scores were less compared to AM+FM conditions in all categories.

In FM +AM condition the highest score was recorded for cow (98%) and the lowest score was recorded for sheep (92.6%) in the category of animals. In mechanical category door knocking scores were 96% whereas school bell has least 86%. Best identified scores in the category of nature was thunder (94.6%) and least identified sound was bee (85.3%). For vehicles it was airplane sound (93.3%) which was best recognized and ambulance (67.3%) was the least recognized. In the category of Human baby cry had a highest score of (96.6%) and cough had least score of (82.6%).

Whereas in AM only condition in animal category cow (81.3%) was the best recognized sound and the least recognized was horse (54%). Door knocking had a score of 100% and the telephone ringing had a score of 70% in the category of mechanical sound. In natural sound category rain sound was best identified (74%) and the poorly identified sound was bee (18.6%). As that was in the AM+FM condition subject were able to identify the sound of air plane (76.6%) best and ambulance (41.3%) was the least. In human category performance in identification of clap sound (86.6%) was best and for brushing (18.6%) sound it was poor.

Discussion

The results were consistent with previous studies where addition of fine structured information with the envelope cues produced better results [10, 15]. Overall, environment sound perception in AM condition resulted poorly compared with AM+FM condition. It is clear that every sound either speech or non speech sound signal normally consists of fine structure and envelope cues. CI user performed well in speech perception using only the envelope cues from the given signal in quiet showed that envelop cues help only when background noise is absent [12, 16, 17]. Fine structure contains the inner details of the signals which give the cues of pitch and sound quality. It helps in realistic listening conditions such as speech with background noise, listening to music and environmental sound perception. Speech perception in adverse listening condition and music perception without fine structure coding showed a poor performance and it is important for pitch perception and sound localization [15, 18, 19]. The poor performance of the AM only sound and better performance for AM+FM sounds indicates that for the best performance of cochlear implant the combination of both AM+FM should be implicated in the cochlear implant devices.

In this study result showed that subjects performed better for AM+FM cues than that of AM only cues for all the categories except for mechanical sounds. It is clear that if the sound signal is provided by both FM as well as AM the performance of sound perception is increased. For mechanical sound the performance of the subjects was almost the same. This poor performance on AM condition can be described on the basis of the acoustic properties of the sounds. Inverso & Limb explained that environmental sounds which are poorly identified by CI users are that because these sounds have temporal and spectral characteristics different than that of speech [6].

The results of this study also correlated with the findings of Looi and Arnephy, where they found a good recognition score for the perception of sounds like door bell and knocking door by CI users which were categorized under mechanical sounds in this study and poor recognition scores for sounds like train and helicopter, they explained this is because the sounds which had good recognition scores had distinctive wave form and discrete wave form and the sounds with poor scores had continuous waveform and no distinctive temporal pattern [9].

The importance of environmental sound training has to be considered in the CI[20].They found that post lingual cochlear implant users with experience, had average ability in identifying environmental sounds. Their speech perception ability was also correlated with their environmental perception ability and they suggest that cochlear implant population may benefit from adding environmental sound training in their rehabilitation program [9]. During the early stages of rehabilitation of newly implanted patents it suggested to practice with environmental sound [21, 22]. The important implication of this study is that fine structure cues should be provided for the CI group which may help in better perception of environmental sounds. Using similar method environmental sound perception can be assessed in CI group. The present method used will also aid in evaluating patients performance in CI group. In future the performance of new cochlear implant users with fine structure cues can be assessed. The identification of environmental sounds in different SNR should be investigated. Since there are numerous differences between acoustic and electric hearing, one should be very careful about applying the results from simulations with normal-hearing listeners to actual implant users.

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