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Original Research Article

Analysis of post implantation speech recognition abilities of children with hearing impairment using cochlear implants

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ABSTRACT

Background: As per census'2011, in India, there are 15, 94,249 children with hearing impairment below 18 years of age. A current method in treating children with hearing impairment is cochlear implantation. The use of cochlear implants aids in improving auditory detection, discrimination, identification and speech recognition. Although, speech recognition is a primary outcome measure in cochlear implantees, there is a paucity of word lists or tests to assess speech recognition abilities, both in local languages in general and Hindi in particular.
Methods: In order to construct word lists comprising of monosyllabic and multisyllabic, easy and hard words, language samples from children (3 - 5 years of age, n = 120) were collected in order to create a database to select stimuli from. The frequency of occurrence and neighborhood density for the words selected from this database was then computed and word lists were constructed. These newly constructed Hindi word lists were administered to 45 cochlear implantees (4.1 to 9 years of age); one year post implantation. Subjects were instructed to listen to the words and repeat them. Responses were scored as number of words correctly repeated.
Results: Cochlear implantees were able to show lexical effects of difficulty, i.e. they achieved higher scores for easy words than those for hard words. However, they were not able to show the same effect for word type.
Conclusions: The newly constructed Hindi word lists appear to be valid lists in assessment of speech recognition abilities of children with hearing impairment using cochlear implants.

Keywords: Monosyllabic, Multisyllabic, Lexically easy, Lexically hard, Speech recognition, Cochlear implantees

INTRODUCTION

According to Census'2011, the number of individuals with hearing impairment is 50, 71, 007; out of which 15, 94,249 are children below 18 years of age. Hearing loss at any age affects the ability of detection, discrimination, identification and perception of sounds and recognition of words and speech. Severe to profound sensorineural hearing loss has a significant effect on development of language, speech production, speech recognition and perception. According to Boothroyd, much of the impact of sensorineural hearing loss depends on the extent to which it affects speech recognition.[1]

A current method in treating individuals with severe to profound sensorineural hearing loss in children is cochlear implantation. The use of multichannel cochlear implants for children with significant hearing loss has been established as a safe and effective means of improving auditory detection, discrimination, identification and perception when benefit from conventional amplification is limited.[2]

Due to the innovative developments in hearing aids and cochlear implants, there has been a renewed interest in speech recognition testing. Although, speech recognition is a primary outcome measure in children using cochlear implants (CI), there has been a paucity of tests to assess speech recognition skills post implantation, both in local languages in general and Hindi in particular. Traditional clinical tests of spoken word recognition, such as the Phonetically Balanced Kindergarten Word List (PBK) yield descriptive information concerning speech perception / recognition performance (i.e., the percent of words or phonemes correctly recognized). Such tests may not be suitable for many children with sensory aids because of the severe-to-profound nature of the children's hearing loss, their young age or limited vocabulary.

As put forth by a number of studies, performance of children with sensory aids on tests of spoken word recognition is influenced by subject characteristics such as age at onset of hearing loss or degree of hearing loss.[3,4] Moreover, results of studies by a number of researchers have revealed that performance on such measures is also affected by the lexical characteristics of the stimulus items. By conducting several experiments, Luce and his colleagues, have provided evidence to show that auditory only spoken word recognition is influenced by factors such as word frequency, neighborhood density (i.e., the number of lexical neighbors for the target word), and neighborhood frequency (i.e., the average word frequency of the words in the lexical neighborhood).[5, 6] It was observed by them that high-frequency words from sparse neighborhoods were recognized with greater accuracy than low-frequency words from dense neighborhoods. Luce et al. put forth the neighborhood Activation Model for enhancing our understanding of spoken word/speech recognition.

Considering the aforementioned factors, two new measures viz. the lexical neighborhood test (LNT) and multisyllabic lexical neighborhood test (MLNT), that were based on the assumptions of NAM were developed by Kirk et al in order to assess spoken word recognition in children with cochlear implants (CIs).[7] These tests were based on two criteria--firstly, the specific words for these lists were selected to be familiar to young children with relatively limited vocabularies. The stimulus words on the LNT and MLNT were selected from the child language data exchange system (CHILDES) database which comprised of productions by children between the ages of three and five years, therefore were assumed to represent early-acquired vocabulary.[8] Secondly, the LNT and MLNT are based on the assumptions of the neighborhood activation model (NAM), which proposed that based on their frequency of occurrence, words are organized into "similarity neighborhoods".[9,10] The NAM further proposed that organization of the word in the mental lexicon is also based on "lexical density" i.e., acoustic-phonetic similarity of words within the lexical neighborhood.

The LNT consists of two lists comprising of 50 monosyllabic words each and the MLNT consists of two 24- item list of multisyllabic words. Further, the tests are so constructed that within each list of the LNT and MLNT, half of the items are lexically easy and half are lexically hard.

In our country, several tests have been developed to assess speech perception/ recognition performance. Speech testing materials available in India were mainly developed for threshold estimation for speech and obtaining speech discrimination scores; for example, Rajshekhar, developed the picture SRT in Kannada for adults and children; Malini, standardized the "NU Auditory Test No. 6" on population who spoke English; Mayadevi, developed a test known as 'Common Speech Perception Test'; Samuel, developed and standardized test material in Tamil language which was phonetically balanced; while speech test material in Bengali language was developed by Ghosh.[11-15] Gathoo adapted the Early Speech Perception Test in Marathi.[16]

The MLNT and LNT tests have their basis in the NAM model. The main concept of this model is that words are retrieved from the mental lexicon depending on the frequency of occurrence of the words and neighborhood density. These factors are dependent on long term memory. Hence, the tests should be constructed and administered in the individual's mother tongue / native language. Hence, there has been a need to develop/ construct these tests in different languages.[7]

In Indian English, LNT was developed by Patro et al for children between 2 to 6 years; The test comprised of two lists, each list consisting 20 lexically 'easy' and 20 lexically 'hard' words.[17] The test was administered on 30 normal hearing children and four hearing impaired children using hearing aids. The study revealed that there existed a significant effect of lexical properties on spoken word recognition scores in both normal hearing children and those who were hearing impaired. Apoorva et al constructed LNT in Kannada in 2012; the test comprised of two word lists consisting of 40 words, 20 lexically 'easy' and 20 lexically 'hard'.[18] 30 normal hearing children and five cochlear implantees responded to the test. It was observed again that lexical effect was seen on scores on spoken word recognition; viz. children got better scores on 'easy' words than on 'hard' words.

It will be interesting to analyze the speech recognition abilities /how children with hearing impairment perceive speech with the help of cochlear implants. There appears to be a paucity of studies using tests like LNT/MLNT in Indian Languages and more so in Hindi, to assess the spoken word / speech recognition abilities of Hindi speaking children with hearing impairment using cochlear implants. There is paucity of lists of words which comprise of "monosyllabic" and "multisyllabic", lexically "easy" and lexically "hard" words which can be used as stimuli to assess speech recognition in children with impairment using cochlear implants. This will further give an understanding of the processes used by the cochlear implantees in recognizing spoken words, thereby enabling making of suitable intervention plans action.

METHODS

First of all, clearance for the study was obtained from the Ethics Committee of AYJNISHD (D) and the study was conducted between 2014 and 2015. In order to construct lists of monosyllabic and multisyllabic words which

comprised of lexically ‘easy’ and ‘hard’ words, the steps taken were as follows: collecting language samples from children (3 to 5 years of age, n = 120) in order to create a database to select stimuli from. This was done by showing 3 validated pictures to the children and they were asked to describe what they saw in the pictures. Their responses were recorded on a digital voice recorder and later transcribed in IPA and analyzed. Analyses of the language samples / utterances of the children were done and monosyllabic and multisyllabic words were selected from the utterances. The frequency of occurrence and neighborhood density for the words selected from this database was then computed. On the basis of frequency of occurrence and neighborhood density words were selected and word lists were made, which comprised of lexically ‘easy’ ad lexically ‘hard’ words as per the instructions given by authors of LNT and MLNT tests. The word lists thus made were recorded as per the requirements of the instructions of the authors of the test.

Both the lists of monosyllabic words and multisyllabic words were divided into lexically “Easy” list and “Hard” lists in the following manner—lexically “Easy” words were those words that had word frequency above the median and had lexical density below the median. The words described as “Hard” had the opposite characteristics viz. having word frequency below the median and lexical density above the median. Thus, the list 1 comprised of 62 monosyllabic words (32 “Easy” words and 30 “Hard” words) and List 2 consisted of 102 multisyllabic words (52 “Easy” words and 50 “Hard” words).

The two newly constructed Hindi word lists were administered to 45 children with hearing impairment using cochlear implants (CWHI) in one ear, with no sensory aid in the other, one year post implant use. All the subjects were included according to following criteria: age range of 4.1 to 9 years with congenital bilateral severe to profound sensorineural hearing loss; using Nucleus 24 Cochlear implant- Freedom or N5 (810) (ACE processing strategy); from Hindi speaking backgrounds (Hindi spoken at home and school). Prior to cochlear implantation, the subjects had used binaural BTE analogue or digital hearing aids and had undergone speech-language intervention for at least one year. Subjects with any of the following were excluded: those with acquired hearing loss; using bilateral cochlear implants or using a hearing aid in the non- implanted ear; having associated impairments or multiple disabilities or coming from multilingual background.

A typical two room sound treated audiometric test setup was used for the study. The subject was seated in the inner (test) room, on a chair with a chair back, with two loudspeakers placed at the left and right of the midline, at 1-meter distance and 45-degree azimuth. Since participants were children with hearing impairment using cochlear implants, the speaker on the side of the implanted ear was used to present the stimuli.

Procedure

A calibrated dual channel diagnostic audiometer was used for testing. The test material was played from a laptop (Sony Vaio VGN-CS14G/B) connected to the external A and external B inputs of the audiometer using a stereo cable. During presentation of the stimulus volume was kept at 100% and was played from the laptop using VLC player. Before each list, gain was adjusted to ‘0’ on the VU meter of each channel. The presentation level used for the word lists was 60 dBHL. Before starting the actual testing children were given instructions using live voice by the tester followed by the recorded stimuli. Subjects were instructed to listen to the words and repeat the words. They were encouraged to guess if they were unsure of the word. Responses were scored as number of words correctly recognized.

RESULTS

Word scores obtained for all the lists were converted to out of 50 for ease of statistics. The converted scores were used in further analysis. It was observed that word scores of three children were very high and were outliers appearing far away from the data points of the other children. Hence, the scores of these three children were excluded from further testing.

The comparative differences between four variables (viz. scores for monosyllabic easy words, monosyllabic hard words, multisyllabic easy words and multisyllabic hard words for children with hearing impairment using cochlear implants- after one year of intervention, are provided graphically in Figure 1.

The boxplots for hard difficulty level reveal lower scores for both mono and multisyllabic words. The scores for monosyllabic words (especially easy words) are higher than the others, however, there are few outliers observed for monosyllabic words – hard.

The descriptive statistics of word scores of 42 children with hearing impairment using cochlear implants after one year of intervention, are illustrated in Tabe 1. It reveals that the mean word scores differ across difficulty level (i.e. “easy” and “hard”, but not across word types (i.e. monosyllabic and multisyllabic). Word scores were highest for monosyllabic words–easy (Mean = 23.53; Std.

Dev= 4.96) and lowest for monosyllabic words – hard (Mean = 19.27; Std. Dev = 5.27).

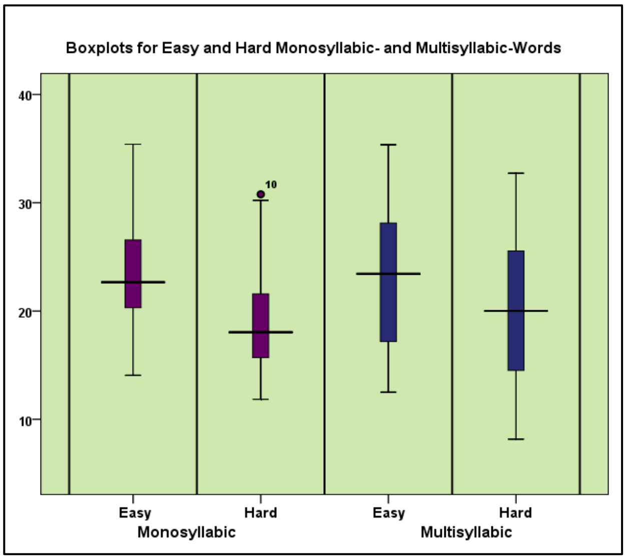

Figure 1: Boxplots for easy and hard monosyllabic and multisyllabic words for children with hearing impairment using cochlear implants (after one year of intervention).

Table 1: Descriptive statistics of word scores of 42 children with hearing impairment using cochlar implants (after one year of intervention).

Variables	Mean	Std. Deviation	N
Monosyllabic Words – Easy	23.53598	4.961613	42
Monosyllabic Words – Hard	19.27374	5.277602	42
Multisyllabic Words – Easy	23.0514	6.054688	42
Multisyllabic Words – Hard	19.6716	6.493404	42

The results of repeated measures of ANOVA (RANOVA) for the word scores of children with hearing impairment one year after intervention are presented in Table 2. The main effect of word type is not significant at p <0.05, F (1, 41) = 0.004 (p >0.05 refer Table 2). However, there appears to be a significant main effect of difficulty level on scores, F (1, 41) = 104.969, p<0.0005. Thus, children differed on difficulty level with respect to overall mean scores.

Table 2: Tests of within-subjects effects for the word scores of children with hearing impairment using cochlear implants (after one year of intervention).

Source	Type IV Sum of Squares	df	Mean Square	F	p-value
Word type	0.079	1	0.079	0.004	0.952
Error (word type)	889.195	41	21.688		
Difficulty level	613.209	1	613.209	104.969*	<.0005
Error (difficulty level)	239.514	41	5.842		
Word type * difficulty level	8.176	1	8.176	1.719	0.197
Error (word type*difficulty level)	194.99	41	4.756		

Table 3: Estimated marginal mean scores for two word types of the children with hearing impairment using cochlear implants (after one year of intervention).

			95% Confidence Interval	
Word type	Mean	Std. Error	Lower Bound	Upper Bound
Monosyllabic words	21.41	0.76	19.86	22.95
Multisyllabic words	21.36	0.92	19.50	23.23

Table 4: Estimated marginal mean scores for two difficulty level related to word scores of children with hearing impairment using cochlear implants (after one year of intervention).

			95% Confidence Interval	
Difficulty level	Mean	Std. Error	Lower Bound	Upper Bound
Easy	23.29	0.80	21.69	24.90
Hard	19.47	0.79	17.89	21.06

However, there was no significant interaction effect between the word type and the difficulty level on scores, F (1, 41) = 1.719, p>0.05. Thus, the difference in the means of difficulty level on one word type was not significantly different from that of the other word type. The estimated marginal means for two levels of word type of the word scores of the children with hearing impairment using cochlear implants, in the no noise condition are presented in Table 3.

The estimated mean score for monosyllabic words (Mean = 21.41, Std. Error = 0.76) is slightly higher than that for multisyllabic words (M = 21.36, Std. Error = 0.92). The difference between the two means (0.05) is present but is very small in the context of the standard errors for the two word types.

The estimated marginal means for two difficulty level related to word scores of children with hearing impairment in no noise condition are presented in Table 4.

The estimated mean score for easy (Mean = 23.29, Std. Error = 0.80) is higher than that for hard (Mean = 19.47, Std. Error = 0.79). The difference between the two means is large (3.82) on the background of their respective standard.

The difference in the means of easy and hard words is statistically significant, F (1,41) = 104.969, p<0.0005. Thus, the mean of easy words is higher than that of the hard words.

The simple effect of word type related to difficulty level related to word scores of hearing impaired children in the no noise condition are presented in Table 5.

The pair wise comparison of word type under each difficulty level allows following conclusions- for easy words the estimated mean score on monosyllabic words is higher only by 0.291 than that of the multisyllabic words, at p >.05 and hence though high, is not statistically significant. similarly, for hard words the mean score of multisyllabic is higher only by 0.382 score and is not statistically significant, p >0.05.

The simple effect of difficulty level related each word type of scores of hearing impaired children in the no noise condition is presented in Table 6.

The pair wise comparison presented in Table 6 allows following conclusions:

For monosyllabic words, easy words have higher mean, by 1.026 points, than that for hard words; the difference is statistically significant. Further, for multisyllabic words, the easy words have means significantly higher (p<0.05) by 1.116 points than that for Hard words; the difference is statistically significant.

For both word type mean easy is higher than that for hard however, effect sizes for the (significant) difference between difficulty level:

r_easy vs hard – 0.719118443 – a difference in the two means is 3.82 and has effect size > 0.5 and < 0.8; Moderate

Important observation is that after one year of intervention the children with hearing impairment using cochlear implants are able to show lexical effects of difficulty through their word scores. In other words, the cochlear implantees are achieving higher scores for Easy words that that for hard words. However, they are not able to show the same effect for word type.

Table 5: Simple effect of word type under each difficulty level related to word scores of children with hearing impairment using cochlear implants (after one year of intervention).

Difficulty level	(I) Word type	(J) Word type	Mean difference (I-J)	Std. Error	p-value	95% confidence interval for differences	
						Lower bound	Upper bound
Easy	Monosyllabic	Multisyllabic	0.485	0.625	0.443	-0.778	1.747
Hard	Monosyllabic	Multisyllabic	-0.398	0.932	0.672	-2.28	1.484

Table 6: Simple effect of difficulty level under each word type related to word scores of children with hearing impairment using cochlear implants (after one year of intervention).

Word type	(I) Difficulty level	(J) Difficulty level	Mean difference (I-J)	Std. error	p-value	95% confidence interval for differences	
						Lower bound	Upper ound
Monosyllabic	Easy	Hard	4.262*	0.406	0.000	3.442	5.082
Multisyllabic	Easy	Hard	3.380*	0.583	0.000	2.203	4.557

DISCUSSION

When lexical effects related to difficulty level are considered the present study's results are similar to those of the study by Kirk et al.[7] The main aim of their research was to study the lexical effects on spoken word recognition by pediatric cochlear implant users. The main purpose of Experiment I was to evaluate whether spoken word recognition was influenced by differences in the lexical characteristics of word lists in children with multichannel cochlear implants.

Children who were not able to demonstrate at least some evidence of word recognition were not included in the study. Thereby, very young children and some children who had used their device for less than 1 year, were eliminated. This was so because word recognition emerges usually 1 year post cochlear implant experience. For inclusion in the study, 28 children who were evaluated met the criterion.

Spoken word recognition was assessed using the three word lists which were also used for the preliminary computational analyses. The test was presented in an order which was counterbalanced across subjects (viz. LNT "easy" word list, LNT "hard" word list, and PB-K). In order that there will be consistency in the number of items across the tests, half of the items on a PB-K list were administered.

The subjects correctly identified 20% to 72% of the words on the LNT "easy" word list and from 12% to 72% on the LNT "hard" list. From the PB-K word lists 4% to 54% of the words were correctly identified. In order to analyze the performance results a two-factor factorial randomized block design was utilized. The analysis of word list, score type (words versus phonemes), the interaction, and the blocking variable of subject was done using percent correct as the dependent variable. Significance was found for word list (F [2, 90] = 50.36, p <0.000l), similar significance was found for score type (F [1, 90] = 308.90, p <0.0001). Further, statistical significance was found for the interaction of word list and score type (F [2, 90] = 6.01, p <0.0035). High significance was found for word list when only word scores were analyzed, F [2, 36] = 31.62, p <0.0001. It was revealed by the pairwise t-tests that "easy" LNT words were identified most accurately. This was followed by "hard" LNT words, and then the PB-K words.

It is observed from the results that lexical knowledge is used by pediatric cochlear implant users while recognizing words. In other words, it was found that performance on spoken word recognition tasks was significantly better on the "easy" word list when compared to that of "hard" word list of the LNT. It can be demonstrated from the results that in spite of having limited vocabularies, children appear to organize words into similarity neighborhoods in long-term memory. They also appear to use this structural information when they are recognizing isolated words. The findings of the present study show that words are recognized in the context of other words in their lexicons by pediatric cochlear implant users.

The results of the present study are also in consonance with the study in Mandarin Chinese by Liu et al.[19] One of the aims of their study was to analyze the performance on open-set word recognition tasks of 230 Mandarin Chinese-speaking children who had received a multichannel cochlear implant (CI). Age at implantation was between 0.9 and 16.0 years, with a mean of 3.9 years. The evaluation of open-set word identification abilities of the children was done using the Standard-Chinese version of the monosyllabic lexical neighborhood test and the multisyllabic lexical neighborhood test. In order to delineate the lexical effects on the open-set word identification in terms of word difficulty and syllable length as the two main factors, a two-way analysis of variance was performed. It was observed that the average percent-correct scores for the disyllabic "easy" list, disyllabic "hard" list, monosyllabic "easy" list, and monosyllabic "hard" list were 65.0%, 51.3%, 58.9%, and 46.2%, respectively. The percentage of words correctly identified was higher for disyllabic words than for monosyllabic words.

The authors concluded that, lexical characteristics of the stimuli influence the open-set word recognition performance of Mandarin Chinese-speaking pediatric CI users. They achieved higher scores for easy words than for hard words; further, they achieved higher scores for disyllabic words than for monosyllabic words.

CONCLUSION

The newly constructed Hindi word lists appear to fulfill the criteria put forth by the original tests and be considered to be valid lists to assess speech recognition abilities of children with hearing impairment using cochlear implants.

The tests are able to elicit lexical effects of Difficulty Level even for children with hearing impairment using cochlear implants. However, the same cannot be said about responses achieved for Word Type. This can be attributed to the fact that the children were tested only one year after meaning use of cochlear implant. Speech recognition abilities improve after more than one year of implant use as put forth by many authors.

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