Qualitative Assessment of Speech Perception Performance of Early and Late Cochlear Implantees

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Abstract The present study aims to provide a qualitative description and comparison of speech perception performance using model based tests like multisyllabic lexical neighborhood test (MLNT) and lexical neighborhood test (LNT), in early and late implanted (prelingual) hearing impaired children using cochlear implants. The subjects comprised of cochlear implantees; Group I (early implantees)— $n = 15$, 3–6 years of age; mean age at implantation—3½ years. Group II (late implantees)— $n = 15$, 7–13 years of age; mean age at implantation—5 years. The tests were presented in a sound treated room at 70 dB SPL. The children were instructed to repeat the words on hearing them. Responses were scored as percentage of words correctly repeated. Their means were computed. The late implantees achieved higher scores for words on MLNT than those on LNT. This may imply that late implantees are making use of length cues in order to aid them in speech perception. The major phonological process used by early implantees was deletion and by the late implantees was substitution. One needs to wait until the child achieves a score of 20 % on LNT before assessing other aspects of his/her speech perception abilities. There appears to be a need to use speech perception tests which are based on theoretical empirical models, in order to enable us to give a

descriptive analysis of post implant speech perception performance.

Keywords Early implantees · Late implantees · Speech perception · LNT · MLNT

Introduction

The use of *cochlear implants* for children with severe to profound sensorineural hearing loss has been established as an effective means of improving auditory detection, discrimination, identification and perception when benefit from conventional amplification is limited [1]. In order to assess the *speech perception* performance of children using hearing aids and/or cochlear implants *special tests* are required. There are many such tests, for example, monosyllable trochee spondee test by Erber and Alenciewicz [2]; Discrimination after Training test, Themeir et al. [3]; auditory perception of alphabet letters test, Ross and Randolph [4]; early speech perception (ESP) test Moog and Geers [5]; lexical neighborhood test (LNT), multisyllabic lexical neighborhood test (MLNT) by Kirk et al. [6].

The LNT and MLNT are used to assess the open-set speech perception performance of children with hearing loss who use cochlear implant or other sensory aids. Except for the LNT and MLNT, none of the other test studies the effect of neighborhood structures of target words on speech perception performance. Besides providing quantitative measures, these tests also provide qualitative assessment in terms of description of parameters and principles which have an influence on open-set speech perception.

A number of studies have used LNT and MLNT to study the effects of lexical category and age at implantation on speech perception skills of cochlear implantees. Luce and

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Pisoni [7] conducted a study, examining whether differences in the lexical characteristics of word lists of MLNT and LNT influence spoken word recognition in these children. The results revealed that pediatric cochlear implants users do use their lexical knowledge in word recognition tasks. That is, spoken word recognition performance was significantly better on the “easy” word list than on the “hard” word list of the LNT.

Various studies on effects of age at implantation on speech perception performance of children using cochlear implants have been conducted *in the West*, for example, studies by Kim [8]; Tyler et al. [9]; Wu et al. [10]; etc. The results of these studies indicated that children who were implanted before 3 years of age performed significantly better in the word scores on both the easy and the hard word lists, when compared to those who were implanted after 3 years of age. Thus the authors concluded that age at implantation influences open-set speech perception.

In the *Indian scenario*, a number of tests have been developed to assess speech perception performance; for example, Picture SRT in Kannada (Rajshekhar, 1976); standardization of the “NU Auditory Test No. 6” on English speaking population, (Malini, 1981); Common Speech Perception Test for Indians, (Mayadevi, 1974); Phonetically balanced test material in Tamil language (Samuel, 1976); Ghosh (1988) developed speech test material in Bengali language.

Presently with a number of State Govt. schemes (Bal Shraman Yojna in Madhya Pradesh and Chattisgarh) and Central Govt. schemes (ADIP CI under AYJNHH, Ministry of Social Justice and Empowerment) a number of children across the country have been provided with cochlear implants. It will be interesting to analyze the speech perception performance of cochlear implantees in the Indian context. Assessing speech perception performance using MLNT and LNT will give us an insight into the strategies/phonological processes used by these children in order to access words from the mental lexicon. There appears to be a dearth of studies assessing speech perception outcome measures post cochlear implants, using speech perception tests in general and MLNT and LNT in particular. Besides the above, there also appears to be a paucity of studies with the objective of studying the qualitative effects of age at implantation on speech perception performance. Hence the need for the present study.

The present study aims to provide a *qualitative* description and comparison of speech perception performance using model based tests like Multisyllabic Lexical Neighborhood Test (MLNT) and Lexical Neighborhood Test (LNT), in early and late implanted (prelingual) hearing impaired children using cochlear implants.

Methods

The subjects comprised of 30 children with congenital (prelingual) bilateral severe (PTA of 71–90 dBHL) or profound (>90 dBHL) sensorineural hearing loss, with no associated sensory and/or motor disorders; with an average to above average performance in their academic skills as per their academic records. The subjects were cochlear implantees using Nucleus 24 Sprint processor (SPEAK strategy) or Freedom processor (ACE strategy).

The children were grouped into *Group 1* comprising 15 children implanted between the chronological age of 3–6 years with age at implantation being between 2 and 4½ years (average age at implantation—3½ years). These children were referred to as “early implantees”. *Group 2* comprised of 15 children implanted between the chronological ages of 7–13 years and their age at implantation was between 5 and 11 years (average age at implantation 5 years). These children were referred to as “late implantees”. Prior to implantation the early implantees and late implantees had used a hearing aid (analogue BTE) and had undergone intervention for at least 1 and 2 years respectively. Post implantation both the groups had received speech-language intervention through the aural–oral mode for a period not less than 1 year after switch on.

In order that misarticulations if any do not bias the test results, a screening of the articulation of the children was done using screening speech articulation test (SSAT) by Mecham [11]. The LNT and MLNT tests were then administered in sound field using the audiometer with facilities for speech audiometry viz. GSI-61, quasi-dual channel (ANSI S-3.6, 1996-calibration standards). The words of the tests were presented in a sound treated room at 70 dB SPL via a monitored live voice, calibrated at the patient’s microphone using a sound level meter and through the speaker which was on the side of the implanted ear of the subject. The child was instructed, “Listen carefully, and repeat what you hear”. The responses were recorded exactly as spoken by the subject, by using narrow phonetic transcription. Performance was scored as percentage of words correctly repeated.

Results and Discussion

The means for the word scores were obtained for both the groups of children on the two word lists each of MLNT and LNT. As per the methodology proposed by the Neighborhood Activation Model (NAM), the percentage of incorrect words were calculated which were residing within the neighborhood of the target words. The incorrect responses were further analyzed to study the differences if any in the phonological processes used by the

early and late implantees in order to arrive at the target words.

The results are presented and discussed under the following headings:

(1) Results obtained on *MLNT*:

- (a) *Word scores* in percentage as obtained on *Easy list of MLNT*.
- (b) *Word scores* in percentage as obtained on *Hard list of MLNT*.
- (c) Analysis of the incorrect responses obtained on words of both *Easy and Hard list of MLNT*, in terms of *within neighborhood responses*.

(2) Results obtained on *LNT*:

- (a) *Word scores* in percentage as obtained on *Easy list of LNT*.
- (b) *Word scores* in percentage as obtained on *Hard list of LNT*.
- (c) Analysis of the incorrect responses obtained on words of both *Easy and Hard list of LNT*, in terms of *within neighborhood responses*.

1(a): Word Scores in Percentage as Obtained on Easy List of MLNT

The means of the word scores as obtained on Easy list of MLNT for both the early and the late implantees are illustrated as a box and whisker plot in Fig. 1.

In Fig. 1 whiskers indicate the minimum scores (0 %) and maximum scores (97.66 %) for early implantees; minimum scores (8.33 %) and maximum scores as (100 %) for the late implantees. The whisker in the box indicates the mean.

As per the Fig. 1, the *mean* of word scores for the *late implantees* was 61.72 % which was significantly *higher* ($p < 0.05$) than that for early implantees whose mean was

Fig. 1 Box and whisker plot for word scores in percentage as obtained on easy list of MLNT

34.81 %. These findings are similar to those obtained in a study conducted by Kirk [12], wherein the early implantees achieved a mean score of 55 % whereas late implantees achieved a range of scores from 20 to 93 %.

1(b): Word Scores in Percentage as Obtained on Hard List of MLNT

The means of the word scores as obtained on Hard list of MLNT for both the early and the late implantees are illustrated as a box and whisker plot in Fig. 2.

As per Fig. 2 whiskers indicate the minimum scores (0 %), and maximum scores (76.66 %) for early implantees; minimum scores (0 %) and maximum scores (100 %) for early late implantees.; the whisker indicating the mean.

The *mean* of the word scores for the *late implantees* at 58.40 % was *higher* than that for the early implantees at 39.84 %. These results are supported by the study of Pisoni [13], in which the late implantees achieved a mean word score of 53 % after 1 year of implant use. The mean word scores achieved by the early implantees in this study are similar to those of subjects (mean word score 42 %) included in the study by Kirk, [12], wherein the speech perception performance of 16 early implantees was compared on LNT and MLNT. In the present study there is a difference in the mean of word scores between the early and late implantees, however, the difference is not significant at 5 % level ($p = 0.087$ i.e. $p > 0.05$).

1(c): Analysis of the Incorrect Responses Obtained on Words of Both Easy and Hard List of MLNT, in Terms of Within Neighborhood Responses

Easy List of MLNT

The percentage of correct and incorrect responses for the words on the Easy list of MLNT achieved by early

Fig. 2 Box and whisker plot for word scores in percentage as obtained on hard list of MLNT

implantees was 34.44 and 65.55 % respectively. Similarly, the late implantees achieved a percentage score of 54.44 and 38.88 % for the correct and incorrect words respectively. It is observed that the early implantees have more percentage of incorrect responses when compared to the late implantees.

The word scores give us quantitative values of the performance of the early and late implantees. However, they do not give us a qualitative description of whether or not the early and late implantees differ in the manner in which they are accessing the words from the mental lexicon. They further do not describe the type of neighborhood strategies used by the early and late implantees in order to recognize the words in an open set. The quantitative values also do not give us any description of the lexical neighborhood characteristics of the incorrect words. Hence, it was further determined whether or not the incorrect responses resided in the *neighborhood of the target words*.

As per NAM framework, it is required that the incorrect responses be further analyzed in terms of whether they are falling within the neighborhood of the target word (Luce [14]; Luce and Pisoni [7]; Chin et al. [15]. As proposed by the authors the incorrect words which would be within the neighborhood of the target would be known as “within target responses”. Hence, further analysis was done in terms of analyzing the incorrect words and calculating to see how many of these incorrect words are “within target responses”. Table 1 presents the number of correct target words and within target responses for both the early and late implantees. The incorrect responses were further analyzed to study whether there were any differences in the phonological processes used by the early and late implantees in order to arrive at the target word (i.e. deletion, addition, substitution or miscellaneous). The phonological processes and their percentage of occurrence used by the early and late implantees are also presented in Table 1.

It is observed from the Table 1 that for the early implantees 67.37 % of the words were either correct target words or within the neighborhood of the target, when compared to late implantees who scored 57.20 % in this respect.

In the study by Chin et al. [15], it was observed that the subjects whose age at implantation was between 3.3 and 7.1 years achieved scores between 44 and 71 % for the responses which were within the neighborhood of the target, this indicates that both the early and the late groups are

indicating a structure of recognizing/accessing the lexicon which is similar to each other. The above results also indicate that the early implantees though they are having more incorrect responses for the word scores, they are able to use various phonological process to access the target word from amongst its neighbors and they are showing higher scores for within neighborhood responses when compared to the late implantees.

From the Table 1 it is also observed that the early implantees use *deletion* as the major phonological process in order to access easy words of MLNT from amongst its neighbors from the mental lexicon, where as the late implantees use *substitution* as their strategy for perceiving easy words of MLNT. Further, it was observed that while the early implantees were deleting initial syllables of the words, the late implantees were deleting final syllables.

Hard List of MLNT

The percentage of correct and incorrect responses for the words on the Hard list of MLNT achieved by early implantees was 41.11 and 63.88 % respectively. Similarly, the percentage of correct and incorrect responses achieved by late implantees was 51.11 and 42.22 % respectively.

Further, the early implantees achieved different scores than the late implantees for the percentage of correct words and within target responses (Table 2). Table 2 also presents the phonological processes and their percentage of occurrence used by the early and late implantees.

It is observed from the Table 2 that for the early implantees 50.16 % of the words and for the late implantees 54.29 % of the words were either the target word or within the neighborhood of the target. The above results are similar to those of a study of Chin et al. [15]. It is also observed that both the groups are using *substitution* as one of the main phonological processes in order to perceive hard words of MLNT.

2(a): Word Scores in Percentage as Obtained on Easy List of LNT

The means of the word scores as obtained on easy list of LNT for both the early and the late implantees are illustrated as a box and whisker plot in Fig. 3.

Table 1 The number of correct words, within target responses and the phonological processes used by early and late implantees to arrive at a target word, for the easy word list of MLNT

Implantees	Correct Target words and within target responses	Phonological process substitution	Phonological process deletion	Phonological process addition	Miscellaneous
Early (%)	67.37	31.35	33.89	3.81	27.50
Late (%)	57.20	47.85	15.71	7.14	35.71

Table 2 The number of correct target words, within target responses and the phonological processes used by early and late implantees to arrive at a target word, for the hard word list of MLNT

Implantees	Correct Target words and within target responses	Phonological process substitution	Phonological process deletion	Phonological process addition	Miscellaneous
Early (%)	50.16	40	24.78	0.86	26.09
Late (%)	54.29	46	13.15	2.63	34.86

In Fig. 3 whiskers indicate the minimum scores (0 %), and maximum scores (68 %) for the early implantees; minimum scores of (4 %) and a maximum scores of (100 %) for the late implantees. The whisker in the box indicates the mean. However, amongst the early implantees, one subject can be considered as an outlier as his/her maximum score is 90 %.

The mean of word scores for the late implantees (51.42 %) was higher than that for the early implantees (mean = 33.98 %). These findings are supported by the study of Kirk et al. [6], where the early implantees achieved a mean score of 29.6 %. The scores obtained by the late implantees are similar to those obtained by subjects in the study of Kirk [12], wherein the subjects achieved a mean score of 45 %. As seen from the Fig. 3, there is a difference in the means of the word scores between the early and late implantees. However, this difference was not statistically significant ($p = 0.103$ i.e. $p > 0.05$).

2(b): Word Scores in Percentage as Obtained on the Hard List of LNT: The Means of the Word Scores as Obtained on Easy List of LNT for Both the Early and the Late Implantees are Illustrated as a Box and Whisker Plot in Fig. 4

As per Fig. 4 whiskers indicate the minimum scores (0 %), and maximum scores (80 %) for the early implantees; minimum score for the late implantees is 0 %, whereas as

the maximum score is 65 %. However, in the late implantees one subject is achieving a higher score viz. 100 % and hence is considered to be an outlier. The whisker in the box indicates the mean.

As observed in Fig. 4, the mean of word scores for the late implantees (47.86 %) is higher than that for the early implantees (34.40 %). These results are similar to those of a study by Kirk et al. [6], wherein subjects achieved mean word scores of 23.4 %. This shows that late implantees are perceiving words on the hard list of LNT in a better manner than the early implantees. However, t test revealed that the $p = 0.155$, indicating no significant difference (i.e. $p > 0.05$) between the mean of word scores of early and late implantees on the hard word list of LNT.

An important observation—there is no significant difference between the early and late implantees with respect to the mean of word scores on both lists of LNT. Kirk et al. [6], put forth that when children are tested for LNT at an earlier age and if children achieve scores which are less than 20 % implies that they have not yet developed word recognition skills. Also children at younger age use different phonological processes to arrive at the target word. This implies that we need to wait until the child achieves a score of 20 % to complete LNT before assessing other aspects of his/her speech perception abilities.

Fig. 3 Box and whisker plot for word scores in percentage as obtained on easy list of LNT **Fig. 4** Box and whisker plot for word scores in percentage as obtained on hard list of LNT

Table 3 The number of correct target words, within target responses and the phonological processes used by early and late implantees to arrive at a target word for the easy word list of LNT

Implantees	Correct Target words and within target responses	Phonological process substitution	Phonological process deletion	Phonological process addition	Miscellaneous
Early (%)	45	29.37	35.01	0.19	30.35
Late (%)	53.45	34.92	24.33	1.85	34.39

Table 4 The number of correct target words, within target neighborhood responses and phonological processes used by early and late implantees to arrive at a target word for the hard word list of LNT

Implantees	Correct Target words and within target responses	Phonological process substitution	Phonological process deletion	Phonological process addition	Miscellaneous
Early (%)	47.60	33	35.4	0.8	29.2
Late (%)	54.26	45.21	16.48	4.78	25.79

2(c): Analysis of the Incorrect Responses Obtained on Words of Both Easy and Hard list of LNT, in Terms of Within Neighborhood Responses

Easy List of LNT

The percentage of correct and incorrect responses for the words on the Easy list of LNT achieved by early implantees was 31.46 and 68.53 % respectively. Similarly, the percentage of correct and incorrect responses achieved by late implantees was 49.60 and 50.40 % respectively. Thus early implantees have more percentage of incorrect responses when compared to the late implantees. Table 3 shows the number of correct target words and within target responses along with the phonological processes used by both the groups.

As observed from Table 3, for early implantees 45 % of the words were either the target word or within the neighborhood of the target, whereas the late implantees achieved a score of 53.45 %.

These results are not similar to those obtained by Chin et al. [15], wherein the speech perception performance of 15 subjects (age range 3.3–7.1 years) on LNT was analyzed. It was observed that 71 % of the easy word responses of the subjects were either a correct response or within the neighborhood of the target. However, the subject selection criteria was different for the study conducted by Chin et al [15]. In their study only those subjects whose scores were more than 20 % on LNT were selected. While in the present study those subjects who scored below 20 % were also included. This would have probably led to lesser scores as compared to those obtained by Chin et al. [15]. From Table 3 it is clear that late cochlear implantees use substitution and miscellaneous (not categorized) phonological

processes more frequently in order to perceive the easy words on LNT, while the early group uses deletion as the phonological process.

Hard list of LNT

The percentage of correct and incorrect responses for the words on the Easy list of MLNT achieved by early implantees was 33.06 and 66.66 % respectively; whereas the late implantees achieved scores of 49.80 and 50.13 % for the correct and incorrect responses. Thus once again early implantees have more percentage of incorrect responses when compared to the late implantees. Table 4 shows the number of correct target words and within target responses along with the phonological processes used by both the groups.

When the correct target words and within target responses were computed, it was observed that for early implantees 47.60 % of the words were either the correct target word or within the neighborhood of the target, when compared to late implantees who scored 54.26 %. The stated results do not support the findings by Chin et al. [15], wherein the subjects achieved a score of 68.4 % as correct responses or within target responses. Thus, results are similar to those obtained for easy word list and similar explanation holds true because only those children who scored above 20 % on LNT were included in the study conducted by Chin et al. [15]. While in the present study those subjects who scored below 20 % were also included thus leading to lesser scores when compared to those obtained by Chin et al. [15]. It is also clear from Table 4 that the early implantees use deletion as a phonological process more frequently to perceive the hard words on LNT, where as the late group uses phonological process of substitution.

The results can be summarized as follows:

When both easy and hard lists of MLNT are considered, although, late implantees have achieved higher word scores than early implantees, the *differences are not statistically significant* at 0.05 level, except for the easy list of MLNT. Similarly, significant difference was not found for word scores on LNT between the two groups.

The late implantees have achieved better scores for word lists of MLNT than for those of LNT. The LNT comprises of monosyllabic words, whereas MLNT comprises two or three syllabic words. This may imply that *late implantees* are making *use of length cues* in order to aid them in speech perception.

Studies do report that cochlear implantees show higher score for lexically easy words when compared to the score for hard words. These studies have excluded children getting a word score less than 20 % on LNT. Similar results in terms of lexical characteristics of words and their influence on speech perception were not observed in the present study. Identifying hard words requires listeners to make fine acoustic–phonetic distinctions among many similar words in dense neighborhoods. Getting no difference between early and late implantees in perceiving easy and hard words may suggest that the children are unable to encode the fine acoustic–phonetic cues in the incoming speech signals. In the present study, if children scoring less than 20 % were excluded, some differences may have been observed between the two groups in perception of hard and easy words.

The early implantees are using more of phonological process of deletion, whereas the late implantees are using substitution to select the target word from amongst its competitors suggesting that they are organizing and accessing the target words from their mental lexicon in a different manner.

Quantitative scores do not give much information of how the cochlear implantees are accessing words from their mental lexicon. Using MLNT and LNT for assessing speech perception gives a descriptive report of the speech perception abilities of cochlear implantees. Hence there appears to be a need to use descriptive tests such as MLNT and LNT for assessing speech perception. This will further enable us to use the information provided by these tests to plan an individual speech perception intervention program to suit the needs of each child.

Along with age at implantation a number of factors appear to have an influence on speech perception performance.

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Compliance with Ethical Standards

Conflict of interest Mrs Anjali R. Kant and Ms Sonal Pathak declare that they have no conflict of interest.

Informed consent Informed consent was obtained from all individual participants included in the study.

Research involving human rights This study involves human participants. All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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