The Use of Lexical Neighborhood Test (LNT) in the Assessment of Speech Recognition Performance of Cochlear Implantees with Normal and Malformed Cochlea

Anjali R. Kant¹ · Arun A. Banik²

Received: 6 April 2017 / Accepted: 27 April 2017 / Published online: 2 May 2017
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Abstract The present study aims to use the model-based test Lexical Neighborhood Test (LNT), to assess speech recognition performance in early and late implanted hearing impaired children with normal and malformed cochlea. The LNT was administered to 46 children with congenital (prelingual) bilateral severe-profound sensorineural hearing loss, using Nucleus 24 cochlear implant. The children were grouped into Group 1-(early implantees with normal cochlea-EI); n = 15, 31/2–61/2 years of age; mean age at implantation—3½ years. Group 2-(late implantees with normal cochlea-LI); n = 15, 6–12 years of age; mean age at implantation—5 years. Group 3-(early implantees with malformed cochlea-EIMC); n = 9; 4.9–10.6 years of age; mean age at implantation—3.10 years. Group 4-(late implantees with malformed cochlea-LIMC); n = 7; 7–12.6 years of age; mean age at implantation—6.3 years. The following were the malformations: dysplastic cochlea, common cavity, Mondini's, incomplete partition-1 and 2 (IP-1 and 2), enlarged IAC. The children were instructed to repeat the words on hearing them. Means of the word and phoneme scores were computed. The LNT can also be used to assess speech recognition performance of hearing impaired children with malformed cochlea. When both easy

and hard lists of LNT are considered, although, late implantees (with or without normal cochlea), have achieved higher word scores than early implantees, the differences are not statistically significant. Using LNT for assessing speech recognition enables a quantitative as well as descriptive report of phonological processes used by the children.

Keywords LNT · Speech recognition · Early implantees · Late implantees · Malformed cochlea

Introduction

The Phonetically Balanced Kindergarten word lists (PB-K), by Haskins [1] till date have remained one of the most important outcome measures for assessing speech recognition in children with hearing impairment using cochlear implant. However, a number of studies have reported poor performance on PB-K word lists by children using cochlear implants. The results of studies by Staller et al. [2] and Fryauf-Bertschy et al. [3] revealed that the mean score on PB-K word list was only 11% words correct for 28 children with approximately 2 years after use of cochlear implants. Due to the advancement in the signal processing strategies, more and more children are being implanted at younger ages. Hence, a more varied range of performance on PB-K word lists has been observed [3–5]. However, overall performance on the PB-K has remained low [3]. As put forth by Kirk et al. [6], one of the possible reasons of poor performance of children with cochlear implants on the PB-K word lists is that the PB-K word lists may contain words that are unfamiliar to young deaf children who typically have very limited vocabularies.

Kirk et al. [7] developed two measures viz. the Lexical Neighborhood Test (LNT) and the Multisyllabic Lexical

✉ Anjali R. Kant
anjali.kant151@gmail.com

Arun A. Banik
arunbanik@rediffmail.com

¹ Department of Speech and Language Pathology, Ali Yavar Jung National Institute of Speech and Hearing Disabilities (Divyangjan) (AYJNISHDD), Mumbai, Maharashtra, India

² Material Development Department, Ali Yavar Jung National Institute of Speech and Hearing Disabilities (Divyangjan) (AYJNISHDD), Mumbai, Maharashtra, India

Neighborhood Test (MLNT), keeping in mind the aforementioned points of discussions. These tests were developed to assess the open-set speech recognition performance of children with hearing impairment using cochlear implants or other sensory aids and 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 [8] which comprised of productions by children between the ages of 3 and 5 years, therefore were assumed to represent early-acquired vocabulary. Secondly, the LNT and MLNT are based on the assumptions of the Neighborhood Activation Model (NAM) [9, 10], which proposed that based on their frequency of occurrence, words are organized into “similarity neighborhoods”. 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. The LNT and MLNT are the only tests that study the effect of neighborhood structures of target words on speech perception/recognition 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 [11].

The results of a study by Luce and Pisoni [10] 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 recognition performance of children using cochlear implants have been conducted *in the West*, for example, studies by Kim [12], Tyler [13], Wu et al. [14], 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.

Over the last decade, the selection criteria for CI have widened and hence includes children with auditory, otologic, and medical problems. Included within this widened group are children with auditory neuropathy spectrum disorder (ANSD), cochleo-vestibular malformations, cochlear nerve deficiency (CND), associated syndromes. In 1987, Jackler

et al. [15, 16], reported that approximately 20% of congenital SNHL is related to anomalous inner ear anatomy. Earlier, cochleovestibular malformations were considered a contraindication to implantation due to concerns about proper electrode insertion, array stability, absent or dysfunctional neurons which might preclude significant auditory perception [17]. A better understanding of cochleo-vestibular malformations, in combination with improved cochlear devices and surgical techniques, have resulted in successful implantation in these patients also [17].

Cochleo-vestibular anomalies are typically classified into seven categories: complete cochlear and labyrinthine aplasia (Michel deformity), cochlear aplasia, common cavity of the cochlea and vestibule, hypoplastic cochlea, Incomplete Partition Type I (IP-I, cystic cochleovestibular malformation or <1.5 basal turns), Incomplete Partition Type II (IP-II Mondini deformity or 1.5–2.75 basal turns), and enlarged vestibular aqueduct (EVA) [16–18].

Cochlear implantation can be successfully achieved in nearly all cochleovestibular malformations, the exceptions being complete labyrinthine and cochlear aplasia [19]. Children with EVA, IP-I, and IP-II tend to perform very well while those with common cavity or hypoplastic anomalies tend to have poorer speech performance due to reduced neural stimulation [15, 17, 20–22].

In the study by Khalessi et al. [23], in 2004, six patients with inner ear malformations underwent implantation at their center and followed up for 27 months. Malformations included one incomplete partition, one common cavity, one narrow internal acoustic canal (IAC) in a patient with Riley–Day syndrome and 3 cases of large vestibular aqueduct. All received multi-channel implants either Nucleus 22 or Clarion device. In all cases, the full length of electrode array was inserted. Open-set speech recognition was shown by four. The one with narrow IAC showed improved awareness to environmental sounds. In the other case (common cavity), the perception tests could not be performed because of very young age.

The aim of a study by Rachotsas et al. [24] was to assess the speech recognition outcome after cochlear implantation in children with malformed inner ear and compare their performance with a group of congenitally deaf children implantees without inner ear malformation. The participants were six deaf children (five boys and one girl) with inner ear malformations who were implanted. These children were matched with six implanted children with normal cochlea for age at implantation and duration of cochlear implant use. All subjects were tested with the battery of tests of listening progress profile (LiP), capacity of auditory performance (CAP), and speech intelligibility rating (SIR). A closed and open set word perception test adapted to the Modern Greek language was also used. In the dysplastic group, two children suffered from CHARGE

syndrome, another two from mental retardation, and two children grew up in bilingual homes. Results revealed that at least 2 years after switch-on, the dysplastic group scored mean LiP 62%, CAP 3.8, SIR 2.1, closed-set 61%, and open-set 49%. The children without inner ear dysplasia achieved significantly better scores, except for CAP which this difference was marginally statistically significant. All of the implanted children with malformed inner ear showed benefit of auditory perception and speech production.

Woolley et al. [25], conducted a case study and intervention study, “with follow-up of 1–5 years, in 4 children with inner ear malformations using Nucleus Implant at ages 3–12 years. Malformations included a common cavity deformity, 2 incomplete partitions, and 1 case of isolated bilateral vestibular aqueduct enlargement”. All patients demonstrated improved performance after implantation. Two patients demonstrated some open-set speech perception. However, the LNT or MLNT have not been used in these studies for assessing speech recognition performance of cochlear implantees.

The aim of the present study was to use the model-based test like LNT, to assess the speech recognition performance after cochlear implantation, in early and late implanted hearing impaired children with normal and abnormal cochlea.

Methods

The subjects comprised of 46 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 implant with Freedom processor (ACE strategy).

The children were grouped into four groups viz. *Group 1* comprising 15 children implanted between the chronological age of $3^{1/2}$ – $6^{1/2}$ years with age at implantation being between 2 and $4^{1/2}$ years (average age at implantation— $3^{1/2}$ years). These children were referred to as “early implantees” (EI). *Group 2* comprised of 15 children implanted between the chronological ages of 6–12 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” (LI). 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. *Group 3* comprised of 9 children with congenitally malformed cochlea 4.9–10.6 years of age implanted between the chronological age of 2.2–4.10 years (average 3.10 years). This *Group* was referred to as “malformed cochlea early

implanted” (EIMC). Seven children with malformed cochlea late implanted (LIMC) formed *Group IV*. They were within the age range of 7–12.6 years and were implanted between 5 and 7.7 years (average age—6.3 years). The following were the malformations present: dysplastic cochlea, common cavity, Mondini’s, Incomplete partition-1 (IP-1), Incomplete partition-2 (IP-2), LVAS, enlarged IAC, bilateral attenuated modiolus, bilateral enlarged aqueduct).

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.

A screening of the articulation of the children was done using screening speech articulation test (SSAT) by Meeham [26], in order that misarticulations if any do not bias the test results. The LNT was 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”. Performance was scored as percentage of words correctly repeated.

Results

The means for the word scores were obtained for both the groups of children on the two word lists of LNT. As per the methodology proposed by the Neighborhood Activation Model (NAM), 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:

- (a) **Word scores and phoneme scores in percentage** as obtained on Easy list of LNT for all the **four groups**.
- (b) **Word scores and phoneme scores in percentage** as obtained on *Easy list and Hard of LNT* for the **Early (EI) and Late Implanted (LI) with normal cochlea**.
- (c) **Word scores and phoneme scores in percentage** as obtained on *Easy list and Hard of LNT* for the Early implanted with malformed cochlea (**EIMC**) and Late Implanted with malformed cochlea (**LIMC**).

- (d) **Word scores and phoneme scores** of Group1 viz. **EI** and Group 3 viz. **EIMC** on Easy and Hard List of LNT.
 - (e) **Word scores and phoneme scores** of Group 2 viz. **LI** and Group 4 viz. **LIMC** on Easy and Hard word List of LNT.
 - (f) Analysis of the incorrect responses obtained on words of both Easy and Hard List of LNT, focusing on within neighborhood responses.
- (a) **Word scores and phoneme scores in percentage** as obtained on Easy list of LNT for all the **four groups**: Means of the word scores and phoneme scores in percentage as obtained on Easy list of LNT for all the four groups are depicted in Table 1.

As per the Table 1, the *mean* of word scores for the Easy list for the *late implantees with normal cochleas* was 49.33% which was *higher* than that for early implantees whose mean was 31%. Similarly, for the Hard list the mean of word scores for the late implantees with normal cochleas was higher than that of the early implantees. These findings are similar to those obtained in a study conducted by Kirk [27], wherein the early implantees achieved a mean score of 55% whereas late implantees achieved a range of scores from 20 to 93%.

A similar trend was observed for the Easy word list for the EIMC and LIMC. However, for the Hard word list the EIMC have achieved higher scores than the LIMC. There is a paucity of studies using LNT to assess speech recognition performance of children with hearing impairment having malformed cochlea and using cochlear implants. It is also observed from the Table 1 that the phoneme scores for all the groups are higher than the word scores.

- (b) **Word scores and phoneme scores in percentage as obtained on Easy list and Hard list of LNT for the Early (EI) and Late Implanted (LI) with normal cochlea.**

The word and phoneme scores in percentage as obtained on the Easy and Hard list of LNT are illustrated in Table 2.

As observed from Table 2, mean phoneme scores obtained by both the groups are higher than those obtained for words. Further, word scores for the *late implantees* (51.42%) were *higher* those of the early implantees (mean = 33.98%) for easy and hard words of both the lists. 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 [27], wherein the subjects achieved a mean score of 45%. As seen from the Table 2, there is a difference in the means of the word scores between the early and late implantees. However, in order to find whether this difference is significant or not the *t* test was administered, the results of which are displayed in Table 3.

It is thus observed that even though the late implantees have higher word and phoneme scores than the early implantees, the difference is not statistically significant ($p = 0.103, 0.155, 0.183, 0.187$; i.e., $p > 0.05$).

- (c) **Word scores and phoneme scores in percentage** as obtained on *Easy list and Hard of LNT* for the Early implanted with malformed cochlea (**EIMC**) and Late Implanted with malformed cochlea (**LIMC**) are displayed in Table 4.

It can be observed from Table 4 that once again phoneme scores are higher than word scores. Word scores for both the list for both the Groups viz. EIMC and LIMC are similar. The point to be noted is that the implanted children with malformed cochlea are also achieving fairly good word and phoneme scores.

The results of the present study are in consonance with the study by Mylanus et al. [28]. In their study the patients with mild cochlear malformation such as an incomplete partition demonstrated a good performance in speech recognition tests. Even the child with the common cavity deformity had some open-set speech perception 1 year after implantation. Further, Graham et al. [29] through their study put forth that in cochlear malformation the range of potential outcomes in terms of speech perception will be similar to the range found in implanted children without cochlear dysplasia.

Table 1 Word scores and phoneme scores in percentage for all four groups

Group	Word score-Easy list	Word score-Hard list	Phoneme score-Easy list	Phoneme score-Hard list
I-EI	31	34.87	64.01	34.67
II-LI	49.33	48.27	73.11	48.27
III-EIMC	38.87	42.56	69.40	71.58
IV-LIMC	44.33	39.58	72.18	66.57

EI early implanted with normal cochlea, *LI* late implanted with normal cochlea, *MC* Malformed cochlea

Table 2 Mean word and phoneme scores in percentage as obtained on Easy and Hard list of LNT for EI and LI

Group	N	Mean	SD
Word scores-Easy list			
EI	15	33.98	23.48
LI	15	51.42	32.40
Word scores-Hard list			
EI	15	34.40	22.80
LI	15	47.86	27.48
Phoneme scores-Easy list			
EI	15	63.48	16.18
LI	15	73.06	21.87
Phoneme scores-Hard list			
EI	15	64.26	16.47
LI	15	73.15	19.44

Table 3 *t* test for assessing significance of difference in scores

	<i>t</i>	<i>df</i>	Significance
Word scores-Easy list	−1.687	28	0.103 NS
Word scores-Hard list	−1.460	28	0.155 NS
Phoneme scores-Easy list	−1.364	28	0.183 NS
Phoneme scores-Hard list	−1.315	28	0.187 NS

Table 4 Mean word scores and phoneme scores of EIMC and LIMC

	Group	N	Mean	SD
Word scores-Easy list	EIMC	9	38.67	13.26
Word scores-Easy list	LIMC	7	44.43	27.42
Word scores-Hard list	EIMC	9	42.56	12.52
Word scores-Hard list	LIMC	7	39.86	24.26
Phoneme scores-Easy list	EIMC	9	69.40	7.77
Phoneme scores-Easy list	LIMC	7	72.18	17.53
Phoneme scores-Hard list	EIMC	9	71.58	6.86
Phoneme scores-Hard list	LIMC	7	66.57	15.61

- (d) **Word scores and phoneme scores** of Group 1 viz. **EI** and Group 3 viz. **EIMC** on Easy and Hard List of LNT: Further, in order to assess whether the difference in the means of the word scores and phoneme scores between the groups was significant or not, the *t* test was administered. Firstly, the *t* test was administered to assess whether there existed a difference in the mean word and phoneme scores of Group 1 viz. EI (Early implanted with normal cochlea) and Group 3 viz. EIMC (Early implanted with malformed cochleas. The results of which are depicted in Table 5.

Table 5 *t* test for assessing significance of difference in the means

	<i>t</i> test		
	<i>t</i> value	<i>df</i>	Significance
Word scores-Easy	−.912	22	0.186 (NS)
Word scores-Hard	−.854	22	0.201 (NS)
Phoneme scores-Easy	−.941	22	0.178 (NS)
Phoneme scores-Hard	−5.426	17.089	0.000 (S)

NS not significant, S significant

As observed from Table 5, there is no significant difference in the mean word scores for the Easy and Hard word lists for Group 1 and Group 3. A similar trend is observed for the mean of phoneme scores for the Easy word list for Group 1 and Group 3. However, for the Hard word list there is a significant difference in the mean phoneme scores of EI (34.67) and EIMC (71.58), where phoneme scores of EIMC were higher than those of EI.

- (e) **Word scores and phoneme scores** of Group 2 viz. **LI** and Group 4 viz. **LIMC** on Easy and Hard word List of LNT: Group statistics were computed for word and phoneme scores for Group 2 (LI) and Group 4 (LIMC). The results are displayed in Table 3. Further, the *t* test was administered to assess whether there existed a difference in the mean word and phoneme scores of Group 2 viz. LI (Late implanted with normal cochlea) and Group 4 viz. LIMC (Late implanted with malformed cochlea). The results of which are depicted in Table 6.

The *t* test was administered to assess whether there existed a difference in the mean word and phoneme scores of Group 2 viz. LI (Late implanted with normal cochlea) and Group 4 viz. LIMC (Late implanted with malformed cochlea). The results of which are depicted in Table 7.

As observed from Table 7, there is no significant difference in the mean word scores for the Easy and Hard word lists for Group 2 and Group 4. A similar trend is observed for the mean of phoneme scores for the Easy and Hard word list for Group 2 and Group 4.

- (f) **Analysis of the incorrect responses obtained on words of both Easy and Hard List of LNT, focusing on within neighborhood responses:** As per Tables 1, 2 and 4, Early implantees both with normal and malformed cochleas are having more number of incorrect responses than the Late implantees. Further, analysis shows 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

Table 6 Group statistics for Group 2 (LI) and Group 4 (LIMC)

	Group	N	Mean	SD	SE of mean
Word scores-Easy list	2	15	49.33	33.55	8.66
Word scores-Easy list	4	7	44.43	27.42	10.36
Word scores-Hard list	2	15	48.27	29.25	7.55
Word scores-Hard list	4	7	39.86	24.26	9.171
Phoneme scores-Easy list	2	15	73.11	21.36	5.51
Phoneme scores-Easy list	4	7	78.18	17.53	6.62
Phoneme scores-Hard list	2	15	48.27	29.25	7.55
Phoneme scores-Hard List	4	7	66.59	15.61	5.90

Table 7 *t* test for assessing significance of difference in the means

	<i>t</i> test		
	<i>t</i> value	<i>df</i>	Significance
Word scores-Easy	.337	20	0.370 (NS)
Word scores-Hard	.660	20	0.258 (NS)
Phoneme scores-Easy	.100	20	0.461 (NS)
Phoneme scores-Hard	−1.542	20	0.69 (NS)

phonological process. For the Hard word lists it is observed that the early implantees use deletion as a phonological process more frequently to perceive the hard words on LNT, whereas, the phonological process of substitution, is used by late implantees. Results are similar to the study by Kant and Pathak [11].

The results can be summarized as follows:

1. The LNT is useful and effective in assessing speech recognition/spoken word recognition performance of children with hearing impairment using cochlear implants. This test can also be used to assess the speech recognition performance of hearing impaired children with malformed cochlea.
2. When both easy and hard lists of LNT are considered, although, late implantees have achieved higher word scores than early implantees, the *differences are not statistically significant*.
3. Results of studies utilizing LNT show that cochlear implantees achieve higher score for Easy words than Hard words. Such a result was not observed in the present study. This may be due to the fact that children are unable to encode the fine acoustic–phonetic cues in the incoming speech signals. This is so because in the present study subjects scoring less than 10% were also included. If children scoring less than 20% were excluded, some differences may have been observed between the four groups in perception of hard and easy words [11].

4. Most children with cochleo-vestibular malformations benefit with CI, and many children show post-implant benefit with speech perception performance.
5. Hang et al. [19] put forth that, ‘it seems likely that in cochlear malformation the range of potential outcomes in terms of development of speech perception and production will be similar to the range found in implanted children without cochlear dysplasia. Similarly, in the present study it was observed that both the Groups viz. One Group of Early and Late Implantees with normal cochleas and the other Group with malformed cochlea achieved similar word scores for both Easy and Hard words of LNT. Thus LNT is one of the important tests in assessing speech recognition performance of cochlear implantees.
6. The LNT is also a descriptive test which enables analysis of phonological processes used by cochlear implantees to access words from the mental lexicon.

Acknowledgements The authors are grateful to Dr. Ashok Kumar Sinha, Director, AYJNISHD(D) for his support and guidance. The authors are grateful to Mr. Rajesh Patadia, Audiologist for the guidance provided and for his expert comments. The authors have not received any grants for this study.

Compliance with Ethical Standards

Conflict of interest The authors 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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