Early auditory preverbal skills development in Mandarin speaking children with cochlear implants

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A R T I C L E   I N F O
Article history:
Received 1 September 2014
Received in revised form 3 November 2014
Accepted 7 November 2014
Available online 15 November 2014

Keywords:
Cochlear implant
Children
Auditory preverbal skill
LittIEARS® Auditory Questionnaire

A B S T R A C T
Objective: The purpose of this study was to investigate the development of auditory preverbal skills in Mandarin speaking infants/toddlers with cochlear implants (CIs).
Methods: Participants were recruited from the Pediatric Audiology Center of Beijing Children’s Hospital, Capital Medical University. A total of 33 children with severe-to-profound hearing loss who received CIs participated in the study. The evaluation tools were LittIEARS® Auditory Questionnaire (LEAQ) and self-designed demographic information questionnaire. Evaluations were administered immediately after the CI was switched on (0-month), and at 1, 3, 6, 9, 12, 18, and 24-month intervals of CI use.
Results: The mean total scores of the LEAQ in 0, 1, 3, 6, 9, 12, 18, and 24-month were 1, 5, 10, 15, 21, 24, 30, and 33 points, respectively. The developmental trajectory of early auditory preverbal skills in the CI children was consistent with the published norm data of the LEAQ, and the expected value even slightly higher than the norms. Analysis showed that the parents’ level of education and age of implantation influenced the final LEAQ score significantly (ANOVA, p < 0.0001).
Conclusions: Auditory preverbal skills improved dramatically after cochlear implantation in the first 2 years of implant use. Early implanted children exhibited a steeper and faster improvement in auditory preverbal developmental compared to the later implanted peers. This study described the developmental trajectories of preverbal auditory skills and confirmed the effectiveness of early implantation on the development of auditory preverbal skills. The results could provide guidance for auditory/speech rehabilitation in Mandarin speaking infants/toddlers who received CIs in their early age.

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1. Introduction

The cochlear implant (CI) has proven to be an effective remediation for children with severe-to-profound sensorineural hearing loss. With the implementation of the universal newborn hearing screening (UNHS) program and deafness–gene screening program, the age of receiving cochlear implantation has been decreased dramatically in recent years with more and more candidates receiving their CIs during infancy [1]. It is critical to assess the early preverbal auditory behavior, which is the basic level in the hierarchical development of the auditory and speech skills. Such skills are also highly related to language acquisition and speech production. Furthermore, preverbal auditory skill predicts spoken word perception and production outcomes in young hearing-impaired children [2]. However, there was limited report on typical auditory preverbal outcome for Mandarin speaking infant/toddler CI users over time due to the lack of age-appropriate evaluation tools. IT-MAIS (Infant-Toddler Meaningful Auditory Integration Scale) is a widely used parent questionnaire to evaluate the early auditory development, however, previous study indicated that IT-MAIS suffered from poor reliability [3].

The LittIEARS® Auditory Questionnaire (LEAQ) was initially developed by Weichbold et al. [4], and has been widely used for auditory preverbal development assessment in infants/toddlers received CIs in several languages [5–10]. It is a parent-oriented questionnaire with 35 yes/no questions and is used to evaluate the early auditory preverbal development for infants/toddlers prior to 24 months of age. The parents completed the questionnaire based on observations of their child’s auditory/speech response in daily life. During scoring, 1 point was awarded for each “yes” answer, and 0 point for each “no” answer. Wie investigated receptive and expressive language development with LittIEARS® in 21 young children who received bilateral CIs between 5 and 18 months of age. The study compared the performance of the CI children with their chronological-age matched, normal-hearing peers. The results showed that the receptive and expressive language
performance of children with CI were comparable to the
normal-hearing children. The study also indicated that the duration of the
CI use was crucial to receptive and expressive language acquisition
[7]. Geal-Dor et al. translated LEAQ into Hebrew and Arabic and
performed the validation, which made it a valid tool for monitoring
the preverbal progress in Hebrew and Arabic children with CIs
[10]. Recently, the questionnaire has been translated and validated
into Mandarin Chinese. The psychometric characteristics of the
Mandarin version of the LEAQ have been validated [11,12]. Wang
et al. demonstrated that the Mandarin version of the LEAQ to be a
reliable, valid, and sensitive tool to evaluate the early auditory
behavior development over time for Mandarin speaking infants/
toddlers under 24 months of age [12]. The purpose of the present
study was to investigate the early auditory preverbal behaviors and
progress trajectory of younger infants/toddlers with CIs with the
Mandarin version of the LEAQ.

2. Material and methods

2.1. Subject

The subjects were recruited from the Pediatric Audiology
Center of Beijing Children’s Hospital, Capital Medical University. A
total of 33 children who had received CIs participated in the study.
The participants comprised 20 boys and 13 girls, the distribution of age
at implantation ranged from 6 to 46 months, with a mean of
24.27 months (SD = 10.66). All the participants met the candidate
criteria according to the guideline of cochlear implantation in
China [13]. Twenty-two children received the CIs in the left ear
(66.7%), 10 in the right ear (30.3%), and one child received bilateral
CIs (3.0%). In terms of CI devices, 27 children received MedEL CIs
(81.8%), and six children received Advanced Bionics (AB) CIs
(18.2%). Informed consents were signed by the parents before the
assessments were administered, and ethics approval was obtained from
the Institutional Review Board of Beijing Children’s Hospital, Capital Medical University.

Radiologically-normal inner ears were diagnosed for 24 of
the children studied (72.7%). However, seven of the children
were diagnosed with large vestibular aqueduct syndrome (LVAS)
by high-resolution computed tomography (HRCT) scans of the
temporal bones. The criteria for an enlarged vestibular aqueduct was
a diameter >1.5 mm, measured at the midpoint on the distal
limb from the common crus and the external aperture into the
posterior fossa [14]. One child suffered from a Mondini malformation
(as diagnosed by HRCT of the temporal bone), and one child
suffered from Michel deformity with a thin auditory nerve (as
diagnosed by HRCT of the temporal bone and inner ear magnetic
resonance imaging (MRI)). Of the children, 30 had no other
disabilities other than hearing impairment (90.9%). For the
remaining three children, one was diagnosed with cerebral palsy
(3.0%), one with auditory neuropathy spectrum disorder (ANSD,
3.0%), and one with leukodystrophy (3.0%). The distribution of the
participants’ living environment showed that 12 children lived in
rural area (36.4%) and 21 children lived in urban area (63.6%). The
distribution of the parents’ level of education revealed that parents
of 4 children had a primary school education (6 years of education,
12.1%), parents of 10 children had junior (9 years of education,
30.3%), parents of 12 children had senior high (12 years of education,
36.4%), and parents of 7 children had post-secondary training (16 years or higher level of education, 21.2%). The detailed
demographic information is shown in Table 1.

2.2. Materials

LEAQ comprises of 35 questions, which can be divided into	hree domains according to the evaluation content. The first is

receptive auditory behavior. An example of these questions is:
Does your child respond to a familiar voice? Such as smiles; looks
towards source; talks animatedly. The second division is semantic
auditory behavior with an example being: When your child is sad
or moody, can he/she be calmed down or influenced by music?
The third and final division is expressive language skills with an
example being: Does your child correctly repeat a sequence of
short and long syllables you have said? Such as “La-la-la-a-a-a”.
The Mandarin version of the questionnaire is shown in Appendix 1.

2.3. Evaluation

The assessment was administered at 0, 1, 3, 6, 9, 12, 18 and
24 months after the CI was switched on. The 0-month session LEAQ
score was served as the baseline measurement. The assessment
was performed by a face-to-face format and before filling in the
questionnaire, an audiologist explained the instructions to the
parents in detail. The parents were told to complete the
questionnaire according to their daily observations. That is, to
response a specific item with “yes” if they had observed the related
behavior at least once, and response with “no” if they had never
observed the behavior or were not sure about whether his/her
child had that behavior. The parents were asked to read the
instructions carefully before they fill in the questionnaire, and they
were encouraged to ask for help if they met any unclear questions
during answering the question. When the parent completed the
questionnaire, the audiologist checked the completeness of the
response. If an infant/toddler was scored maximum (35) in two
successive evaluations, we considered his/her first hearing age and
core as the endpoint.

3. Results

The mean LEAQ score was 33 at 24 months of hearing age, with
a range of 24 to 35. This group of children got near zero score (mean
score was 1 point) at the beginning of the study (immediately
after the CI was switched on, that is, hearing age was 0 month).
Specifically, 22 children received zero point at 0-month session,
accounting for 66.7% of the whole participants. The other
11 children also received floor scores, most ranging from 1 to
4 points. Most children showed a dramatically improvement over
hearing age (ANOVA, p < 0.001). By hearing age of 12 months,
two children have achieve full scores (35 points), and the number of
children who achieving full scores of at 18 and 24 months of
hearing age was 6 and 11, corresponding percentages were 18.2%
and 33.3%, respectively. The development of LEAQ score as hearing
age is plotted in Fig. 1.

In order to investigate the differences between the CI children
and their hearing age matched, normal-hearing peers, we
compared the present result with the published norm data of
LEAQ. The norm curve of LEAQ in German was established by
Coninx et al. [11] through assessing a group of 218 German
and Austrian normal hearing infant/toddlers (age ranged from 5 days
to 24 months). The Mandarin version of LEAQ's norm data was
established recently by Wang et al. [12], which was obtained from
157 normal hearing infants/toddlers with age ranging from 2 to
24 months. Generally, the present group of children’s early
auditory skills development trajectory was consistent with the
published norm data of the LEAQ, and the expected value even
slightly higher than the norms (except the baseline). The
comparison between the present study and the published LEAQ
norms is shown in Table 2.

To examine any potential affecting factors on early auditory
preverbal development, we analyzed the effects of the child’s living
environment, education level of the parents, and age of cochlear
implantation on the final performance. A three-way ANOVA
The implantation LVAS, (CP, score.

Table 1
Subject demographic information.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Gender</th>
<th>Age at implantation (month)</th>
<th>Type of implant</th>
<th>Implant ear</th>
<th>Etiology</th>
</tr>
</thead>
<tbody>
<tr>
<td>S01</td>
<td>M</td>
<td>27.0</td>
<td>Medel_COMBI40+</td>
<td>R</td>
<td>LVAS</td>
</tr>
<tr>
<td>S02</td>
<td>M</td>
<td>18.0</td>
<td>Medel_SONATA</td>
<td>R</td>
<td>Mondini</td>
</tr>
<tr>
<td>S03</td>
<td>F</td>
<td>13.0</td>
<td>Medel_SONATA</td>
<td>L</td>
<td>Unknown</td>
</tr>
<tr>
<td>S04</td>
<td>M</td>
<td>11.0</td>
<td>Medel_PULSAR</td>
<td>R</td>
<td>Unknown</td>
</tr>
<tr>
<td>S05</td>
<td>M</td>
<td>29.0</td>
<td>Medel_PULSAR</td>
<td>R</td>
<td>Unknown</td>
</tr>
<tr>
<td>S06</td>
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<td>Medel_SONATA</td>
<td>L</td>
<td>LVAS</td>
</tr>
<tr>
<td>S07</td>
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<td>20.0</td>
<td>Medel_PULSAR</td>
<td>R</td>
<td>CP</td>
</tr>
<tr>
<td>S08</td>
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<td>Medel_PULSAR</td>
<td>L</td>
<td>Unknown</td>
</tr>
<tr>
<td>S09</td>
<td>M</td>
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<td>Medel_PULSAR</td>
<td>L</td>
<td>LVAS</td>
</tr>
<tr>
<td>S10</td>
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<td>Medel_PULSAR</td>
<td>L</td>
<td>LVAS</td>
</tr>
<tr>
<td>S11</td>
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<td>19.0</td>
<td>Medel_SONATA</td>
<td>R</td>
<td>Unknown</td>
</tr>
<tr>
<td>S12</td>
<td>M</td>
<td>22.0</td>
<td>Medel_PULSAR</td>
<td>L</td>
<td>Unknown</td>
</tr>
<tr>
<td>S13</td>
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<td>46.0</td>
<td>Medel_PULSAR</td>
<td>L</td>
<td>Unknown</td>
</tr>
<tr>
<td>S14</td>
<td>M</td>
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<td>Medel_PULSAR</td>
<td>L</td>
<td>Unknown</td>
</tr>
<tr>
<td>S15</td>
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<td>Medel_PULSAR</td>
<td>L</td>
<td>Unknown</td>
</tr>
<tr>
<td>S16</td>
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<td>36.0</td>
<td>Medel_SONATA</td>
<td>L</td>
<td>Unknown</td>
</tr>
<tr>
<td>S17</td>
<td>M</td>
<td>15.0</td>
<td>AB_HiRes 90K</td>
<td>B</td>
<td>LVAS</td>
</tr>
<tr>
<td>S18</td>
<td>F</td>
<td>20.0</td>
<td>Medel_PULSAR</td>
<td>R</td>
<td>Unknown</td>
</tr>
<tr>
<td>S19</td>
<td>F</td>
<td>26.0</td>
<td>Medel_SONATA</td>
<td>R</td>
<td>Leukodystrophy</td>
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<tr>
<td>S20</td>
<td>M</td>
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<td>Medel_COMBI40+</td>
<td>L</td>
<td>LVAS</td>
</tr>
<tr>
<td>S21</td>
<td>M</td>
<td>17.0</td>
<td>Medel_PULSAR</td>
<td>L</td>
<td>Unknown</td>
</tr>
<tr>
<td>S22</td>
<td>M</td>
<td>22.0</td>
<td>Medel_SONATA</td>
<td>L</td>
<td>Unknown</td>
</tr>
<tr>
<td>S23</td>
<td>M</td>
<td>20.0</td>
<td>Medel_SONATA</td>
<td>L</td>
<td>Unknown</td>
</tr>
<tr>
<td>S24</td>
<td>M</td>
<td>46.0</td>
<td>Medel_COMBI40+</td>
<td>L</td>
<td>Unknown</td>
</tr>
<tr>
<td>S25</td>
<td>F</td>
<td>26.0</td>
<td>Medel_SONATA</td>
<td>L</td>
<td>Unknown</td>
</tr>
<tr>
<td>S26</td>
<td>M</td>
<td>12.0</td>
<td>Medel_PULSAR</td>
<td>L</td>
<td>Unknown</td>
</tr>
<tr>
<td>S27</td>
<td>M</td>
<td>42.0</td>
<td>Medel_PULSAR</td>
<td>R</td>
<td>LVAS</td>
</tr>
<tr>
<td>S28</td>
<td>F</td>
<td>14.0</td>
<td>Medel_PULSAR</td>
<td>L</td>
<td>Unknown</td>
</tr>
<tr>
<td>S29</td>
<td>M</td>
<td>16.0</td>
<td>Medel_SONATA</td>
<td>L</td>
<td>Unknown</td>
</tr>
<tr>
<td>S30</td>
<td>F</td>
<td>38.0</td>
<td>AB_HiRes 90K</td>
<td>R</td>
<td>Unknown</td>
</tr>
<tr>
<td>S31</td>
<td>M</td>
<td>6.0</td>
<td>Medel_SONATA</td>
<td>L</td>
<td>Unknown</td>
</tr>
<tr>
<td>S32</td>
<td>F</td>
<td>15.0</td>
<td>AB_HiRes 90K</td>
<td>L</td>
<td>ANSD</td>
</tr>
<tr>
<td>S33</td>
<td>F</td>
<td>21.0</td>
<td>AB_HiRes 90K</td>
<td>L</td>
<td>Michel, thin CN 8</td>
</tr>
</tbody>
</table>

ANS, auditory neuropathy spectrum disorder; CP, cerebral palsy; LVAS, Large Vestibular Aqueduct Syndrome.

This revealed that both the education level of the parents and age of implantation significantly influenced the final LEAQ score \((p < 0.0001)\), and the factor of living environment, also affected the final LEAQ performance, although with a modest level \((p = 0.043)\). The data showed that early implanted infants/toddlers exhibited lower initial scores (close to zero), however they showed a steeper progress and achieved full score at an early hearing age compared to their later implanted peers. In this study, the youngest children (S31 and S26), who received CI at 6 and 12 months of age, received a zero score at the beginning of the study, while they achieved full score by 12 months after CI use. In contrast, the later implanted children showed a relatively higher score at the beginning of the investigation. For example, participants S13 and S24, both of these two children received CI at 46 months of age, their initial LEAQ scores were 7 and 9 points, however they progressed at a slower rate and spent longer time to achieving full score, the corresponding hearing ages were 22, and 24 months, respectively.

This group of participants included seven children with Large Vestibular Aqueduct Syndrome (LVAS), a common inner ear deformity [14]. Cochlear implantation had been proved to be an effective interventional approach for isolated LVAS candidates to

Fig. 1. Development of LEAQ score as a function of hearing age (duration of implant use). The X-axis represents the hearing age (month), the Y-axis represents the LEAQ score.

Table 2
Comparison of the LEAQ scores between present study and the published Norms.

<table>
<thead>
<tr>
<th>Hearing age (month)</th>
<th>Present study ((N=33))</th>
<th>Mandarin norms ((N=157))</th>
<th>Germany norms ((N=218))</th>
<th>EV</th>
<th>MV</th>
<th>EV</th>
<th>MV</th>
<th>EV</th>
<th>MV</th>
</tr>
</thead>
<tbody>
<tr>
<td>s0</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>s1</td>
<td>5</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>s3</td>
<td>10</td>
<td>0</td>
<td>9</td>
<td>0</td>
<td>3</td>
<td>9</td>
<td>3</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>s6</td>
<td>15</td>
<td>6</td>
<td>14</td>
<td>5</td>
<td>8</td>
<td>15</td>
<td>8</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td>s9</td>
<td>21</td>
<td>10</td>
<td>19</td>
<td>10</td>
<td>20</td>
<td>13</td>
<td>10</td>
<td>20</td>
<td>13</td>
</tr>
<tr>
<td>s12</td>
<td>24</td>
<td>13</td>
<td>23</td>
<td>14</td>
<td>24</td>
<td>17</td>
<td>14</td>
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<td>s18</td>
<td>30</td>
<td>20</td>
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<td>21</td>
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<td>24</td>
</tr>
<tr>
<td>s24</td>
<td>33</td>
<td>24</td>
<td>33</td>
<td>24</td>
<td>33</td>
<td>27</td>
<td>24</td>
<td>33</td>
<td>27</td>
</tr>
</tbody>
</table>

EV: Expected value; MV: minimum value. The expected value refers to the mean value of the hearing-age appropriate LEAQ score.
acquire practical audibility, speech and communication skills [15,16]. The present study revealed that there was no difference between the subjects with and without LVAS on LEAQ performance (Independent-Samples T Test, \( p > 0.05 \)). This result indicated that infants/toddlers with isolated LVAS followed a comparable trajectory with the normal inner ear pediatric CI users in early auditory skills development, which was consistent with the previous report [16]. These findings reinforced the evidence of the effectiveness of cochlear implantation for LVAS children.

Child No.32 (S32) was diagnosed with ANSD pre-operation and her individual data exhibited rapid progress over the 24 months of CI use. She received a full score by 22 months of device use. Child No.33 (S33) combined with Michel malformation and thin auditory nerve, despite the implant was in normal function and the program was optimized, her LEAQ performance lagged compared to her normal-inner-ear peers. She received 24 points by 24 months of CI use.

For child No.2 (S2), who combined with Mondini dysplasia, he also exhibited a delay in preverbal auditory development, the 6-month, 12-month, and 24-month of LEAQ scores were 7, 16, and 26 points, respectively. Those LEAQ scores were slightly higher than the minimal value but lagged behind the expect value, which indicated that the early auditory skills developed delayed in this child with Mondini malformation.

4. Discussion

This study described the age-dependent early preverbal auditory performance using LEAQ in 33 younger children with CIs. We compared the LEAQ performance with their hearing age matched norm curve of normal-hearing children [11,12]. Generally, the present study showed that this group of children exhibited a similar developmental trajectory with their hearing age matched normal hearing peers and even showed a steeper progress rate than the normal hearing group once they access to auditory stimulation. This finding was comparable to Kishon-Rabin’s report [17]. Kishon-Rabin et al. compared the productions of severe/ profound hearing-impaired infants pre- and post-implantation (\( N = 24 \), age ranging from 8 to 23 months) with those of normal-hearing infants (\( N = 163 \), age ranging from 0.5 to 20 months). Their study indicated that although the hearing-impaired infants exhibited very limited auditory skills before cochlear implantation, their post-operation performance was as good as or even better than their hearing age matched, normal-hearing peers. Furthermore, they also found a strong correlation between the auditory skills and the prelexical vocalizations. The findings indicated the importance of early auditory stimuli to auditory and pre-verbal acquisition. These studies reinforced the necessity and importance of early exposure to auditory cues in hearing impaired infants/toddlers, and the benefits of CIs to severe/profound hearing-impaired infants. It was worth to mention that the progress of the auditory and preverbal skills could not be entirely attribute to CI benefits, the accumulation of auditory experience and maturation of cognitive abilities may also play a role.

The benefits of early implantation on language development have been widely documented [18–21]. However, the evidence of early implantation on preverbal auditory skills was limited. The present study showed that the early implanted children exhibited lower initial LEAQ scores while they progressed faster and achieved the highest at an early hearing age. By contrast, the later implant group showed a higher score at the beginning, but they progressed at a slower rate and reached the plateau with longer time of CI use. This finding demonstrated the importance of early exposure to sound for auditory preverbal development, which was consistent with another previous report [2]. Taït et al. assessed the auditory preverbal skills in 99 children. According to the age of implantation, the participants were classified into three groups: children who received their CIs between 1–2 years; 2–3 years, and 3–4 years, respectively. The children’s preverbal skills were investigated by video recording, and were analyzed in three domains, i.e., turn taking, autonomy, and auditory awareness. Their study found that auditory preverbal skills improved significantly faster in children who implanted CIs between 1–2 years of age, which proved the effectiveness of early implantation on auditory preverbal skills development. The lower initial score was comprehensible and could be explained as follow: first, younger infants/toddlers had fewer auditory experiences compared to their later implanted peers, which lead to the lower scores at the beginning of the observation. Second, the lower initial score may also partly due to the less mature of the cognitive ability of the younger implanted group.

The present study demonstrated that there was no difference between the participants with LVAS and those with a normal inner ear on LEAQ performance (Independent-Samples T Test, \( p > 0.05 \)), which indicated that infants/toddlers with isolated LVAS followed a comparable auditory preverbal trajectory with the normal inner ear pediatric CI users. Chen et al. compared the auditory skills in children with LVAS and normal inner ear who received CIs [16]. Chen et al.’s retrospective study investigated three auditory skills by IT-MAIS, they were increased vocalization with device use, alerting to sounds in everyday living environments, and deriving meaning from sound, respectively. Their study found that children with LVAS exhibited comparable auditory skills with those with a normal inner ear. The present study proved that the auditory preverbal skills in infant’s with LVAS did not delayed compared to their normal inner ear peers who implanted with CIs. These studies have demonstrated that cochlear implantation was an effective intervention to infants/toddlers with LVAS, which provide the opportunity to acquire equivalent auditory preverbal skills for this kind of infants/toddlers.

In the present study, Child No.32 (S32) was diagnosed with ANSD prior to cochlear implantation. She seemed to follow a normal auditory preverbal development post implantation. There were several reports focused on the speech and language outcome in ANSD children received with CIs recently [22–24]. Those reports also demonstrated that there was no significant difference in post implantation speech and language performance between ANSD and cochlear hearing loss. These findings indicated that a CI was a reasonable option for children with ANSD and received minimum benefit from the conventional acoustic amplification.

We performed a one-way ANOVA test to examine the effect of parent’s level of education on the auditory preverbal performance. The analysis revealed that parents’ level of education influenced the LEAQ score significantly (ANOVA, \( p < 0.0001 \)). Results indicated that the educational level of the parents, especially the maternal educational level would be a predictor of the auditory preverbal outcomes. Parents with high educational level usually pay more attention to their children’s auditory speech rehabilitation, performance progress, and the communication with the professionals, which in turn promote the acquisition of the auditory preverbal skills of the children. Furthermore, we also found that parents with high level of education usually found the occurrence of hearing loss earlier, which led to early access to auditory stimulation. Maternal educational level was proved to be a significant predictor for the outcomes of the children with CIs in a recent study [25].

5. Conclusion

The Mandarin version of LEAQ was a well established tool for assessing the age-dependent auditory preverbal performance in hearing-impaired children who have received CIs. Results
demonstrated that infants/toddlers who received CI at an early age (i.e., before 12 month of age) exhibited a lower initial scores (nearly zero), while they progressed at a steeper rate and achieved full score at a shorter time of device use compared with the later implanted peers. This study confirmed the effectiveness of early implantation, educational level of parents on auditory preverbal skills development. The preverbal auditory skills development and potential influencing factors could provide guidance for the professionals working on preverbal auditory rehabilitation program for Mandarin speaking infants/toddlers with CIs.

Acknowledgements

This research was supported by National Natural Science Foundation of China (81300838, 81170916), Beijing Natural Science Foundation (7144212), and Beijing NOVA Program (xx2014B059).

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ijpolor.2014.11.010.

References