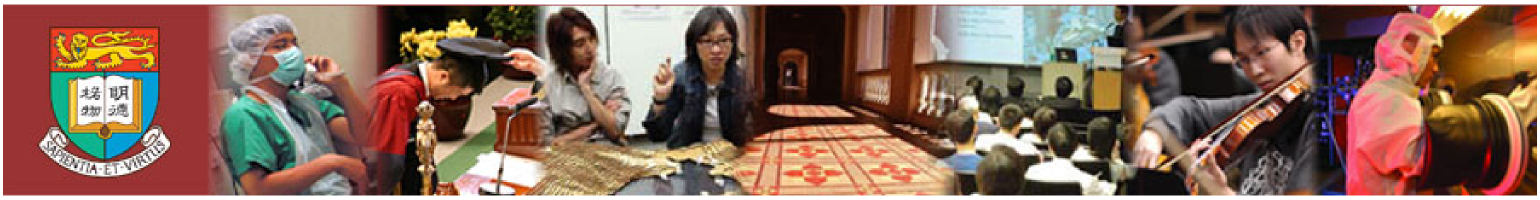

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Speech perception in Mandarin-speaking children with cochlear implants: a systematic review

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Abstract

Objective: This paper reviewed the literature on the trajectories and the factors significantly affecting post-implantation speech perception development in Mandarin-speaking children with cochlear implants (CIs). *Design:* A systematic literature search of textbooks and peer-reviewed published journal articles in online bibliographic databases was conducted. *Study sample:* PubMed, Scopus, and Wiley online library were searched for eligible studies based on predefined inclusion and exclusion criteria. Results: A total of 14 journal articles were selected for this review. A number of consistent results were found. That is, children with CIs, as a group, exhibited steep improvement in early speech perception, from exhibiting few prelingual auditory behaviors before implantation to identifying sentences in noise after one year of CI use. After one to three years of CI use, children are expected to identify tones above chance and recognition of words in noise. In addition, early age at implantation, longer duration of CI use and higher maternal education level contributed to greater improvements in speech perception. *Conclusions*: Findings from this review will contribute to the establishment of appropriate short-term

developmental goals for Mandarin-speaking children with CIs in mainland China and clinicians could use them to determine whether children have made appropriate progress with CIs.

Key words: Behavioral measures, cochlear implant, pediatric, speech perception

Abbreviations:

CI	Cochlear implant
HI	Hearing impairment
IT-MAIS	Infant-toddler Meaningful Auditory Integration Scale
MAIS	Meaningful Auditory Integration Scale
MESP	Mandarin Early Speech Perception
MPSI	Mandarin Pediatric Speech Intelligibility
LNT	Monosyllabic Lexical Neighborhood Test
MLNT	Multisyllabic Lexical Neighborhood Test
S/Ns	Signal-to-noise ratios
HAT	Hearing aid trial
MEL	Maternal education level
CDaCI	Childhood Development after Cochlear Implantation
PBK	Phonetically Balanced word Lists-Kindergarten
HINT	Hearing In Noise Test

Introduction

It is estimated that there are 27.8 million people with some levels of hearing impairment (HI) in mainland China. According to the Ministry of Health (2001), 115,000 children under age 7 were identified with severe to profound HI. In addition, 30,000 infants are born with significant HI annually. Cochlear implantation is becoming a more common intervention for these children in Mainland China. About 7,000 people were expected to receive cochlear implantations in Mainland China each year and 85% of them were under 7 years of age (Liang & Mason, 2013). As of 2015, the Chinese government alone had funded implants for 18,600 children (Y. Chen, Wong, Zhu, & Xi, 2016). However, this number does not quite address the incumbent hearing needs. Tong and Lee (2009) estimated that 36,000-192,000 implantations should be performed each year if we were to reach the level of expecting intervention of developed countries.

Test materials for assessing speech perception outcomes with cochlear implants

Successful case management and intervention of children with cochlear implants (CIs) require reference to appropriately defined developmental goals established via studies of outcome measurement in pediatric CI recipients. Because a single measure is subject to ceiling or floor effects, a battery of hierarchical tests is often used to track the development of speech perception. Such a test battery has been used in the Childhood Development after Cochlear Implant (CDaCI) study and has been proved to be a practical strategy for tracking emergent skills in pediatric implantees (Eisenberg et al., 2006)

Outcome measurement in Mainland China is limited by the availability of measurement tools. At present, the only test battery available for evaluating preschool children were those developed following the CDaCI protocol. This battery includes Mandarin versions of the Infant-toddler Meaningful Auditory Integration Scale (IT-MAIS) (Zheng, Soli, et al., 2009b); the Meaningful Auditory Integration Scale (MAIS) (Zheng, Soli, et al., 2009b); the Mandarin Early Speech Perception (MESP) test (Zheng, Meng, et al., 2009); the Mandarin Pediatric Speech Intelligibility (MPSI) test (Zheng, Soli, et al., 2009a); the Mandarin versions of the Monosyllabic Lexical Neighborhood Test (LNT) and the Multisyllabic Lexical Neighborhood Test (MLNT) (Liu et al., 2013).

The Mandarin versions of the IT-MAIS and the MAIS are parent questionnaires of early prelingual auditory development for very young children. While the IT-MAIS targets infants under age three, the MAIS evaluates auditory behavior in children aged from 3 to 6 years of age. Both the MAIS and the IT-MAIS contain a total of 10 questions, with the first two being different to suit the expected auditory behavior of children at different ages and the remaining eight being identical. Results from the IT-MAIS and the MAIS are often combined for ease of analysis (Zheng, Soli, et al., 2009b).

The MESP consists of two versions, the standard version (SV-MESP) and low-verbal version (LV-MESP), and both are closed-set speech identification tests. There are six categories in the SV-MESP and four categories in the LV-MESP. The first three categories in the two versions are the same. They are Category 1 - Speech

Detection, Category 2 - Pattern Perception, and Category 3 - Spondee Perception. However, Category 4 on the LV-MESP refers to Simple Word Perception while Category 4 on the SV-MESP examines Vowel Perception. The SV-MESP has two more categories: Category 5 - Consonant Perception, and Category 6 - Tone Perception. Unlike the SV-MESP, which uses pictures and recorded test materials, the LV-MESP uses actual objects, live-voice materials and a small response set (i.e., four items). Therefore, the LV-MESP is more appropriate for younger children with limited vocabulary. Both versions are hierarchical in that a child progresses to the next category if his/her score on the current category is significantly above chance. The LV-MESP is used when children could not be evaluated using the SV-MESP. Both versions are scored to report the highest category that a child is able to achieve scores above chance level (Zheng, Meng, et al., 2009).

The MPSI evaluates closed-set sentence identification in quiet and in noise. It is introduced when category 3 or 4 on the MESP is achieved. Children are expected to select the target from a picture plate depicting six sentences. Testing with the MPSI is attempted in quiet, and then in the presence of a competing sentence at signal-to-noise ratios (S/Ns) of +10, +5, 0, -5 and -10 dB. The MPSI is scored to report the most challenging test condition that a child is able to achieve scores significantly above chance level.

The Mandarin versions of the LNT and the MLNT examine open-set word recognition. The LNT consists of three monosyllabic easy word lists and three monosyllabic hard words lists, with 20 items in each list. Similarly, the MLNT consists of three disyllabic easy word lists and three disyllabic hard word lists. The "easy" words are spoken frequently and have low neighborhood density (i.e., there are few phonemically similar words around the target word). On the contrary, the "hard" words exhibit low word frequency and high neighborhood density (Liu et al., 2015).

Even with this CDaCI protocol in place, no single study has used all measures to track speech perception in Mandarin-speaking children with CIs. Most importantly, there is no systematic documentation of the development of speech perception in Mandarin-speaking children using CIs. One aim of this review is then to synthesize evidence from studies using these measures as an attempt to establish developmental goals for this population.

Factors affecting speech perception

Studies have always shown a wide range of speech perception skills among English-speaking implant recipients. Many factors have been identified to affect the development of speech perception of children with CIs. Individual characteristics such as late age at implantation, presence of other disabilities, abnormal inner ear structure, poor preoperative hearing level and central processing problems are related to poorer speech perception with CI, whereas longer duration of CI use correlates with better outcomes. Educational variables such as more training and the use of oral mode of communication would promote speech understanding ability. CI device characteristics such as a well-fitted map, as evidenced by a wide dynamic range and optimal growth of loudness characteristic, are expected to yield good speech perception performance. In terms of family characteristics, higher family income, smaller family size, and higher parental/family involvement contribute to better speech perception skills (Geers, Brenner, & Davidson, 2003).

However, factors contributing to speech perception in Mandarin-speaking children with CIs are not necessarily identical to those reported among their English-speaking peers because of differences in linguistic, cultural and socioeconomic factors (Y. Chen, Wong, Zhu, & Xi, 2015).

Linguistically, Chinese is a tonal language where tones are used to convey lexical meaning within syllables, in contrast to changes in pitch to express emotions in English. Tone information is particularly important for tonal language and speech recognition in noise (Mao & Xu, 2016). Thus, poor pitch information conveyed by CIs poses a special challenge for Mandarin speakers. In addition, vowels may contribute more in perceiving Mandarin sentences than in perceiving English sentences. F. Chen, Wong, and Wong (2013) reported a 3:1 advantage for vowel-only sentences over consonant-only sentences while a 2:1 advantage has been reported in English (Cole, Yan, Mak, & Fanty, 1996). Thus, the acoustic information carried by these two languages is dissimilar.

Culturally, the stigma associated with deafness and the fragmentation of hearing healthcare services have prevented the formation of a deaf culture which use sign languages as the main means of communication. This has resulted in an exclusive use of oral mode of communication in mainland China (Liang & Mason, 2013). In addition, there has been a long Chinese tradition of families, including those with limited financial resources, investing in the education of their children. This tradition is further enhanced by the one-child policy dated back in 1979. This guarantees a high level of family involvement (Liang & Mason, 2013), which plays a crucial role in enhancing speech perception development in a country with weak hearing service infrastructure (Y. Chen et al., 2015). Geers et al. (2003) also found that children from smaller families tend to achieve better speech perception outcomes than those from bigger families (Geers et al., 2003). However, it is not uncommon for many children living in rural China to be left under the care of their grandparents when their parents work in the cities. The grandparents have little education and often do not understand the implications of providing a rich language environment.

Socioeconomically, although developing at a fast rate, mainland China is still a developing country. The infrastructure in Mainland China is often nascent (Liang & Mason, 2013). Universal hearing screening has yet to cover all provinces and municipalities and many implantees have not undergone a hearing aid trial (HAT) before implantation (Y. Chen et al., 2015). Mandarin-speaking children may thus receive CIs at a later age and pre-implant auditory stimulation may be limited.

Therefore, as the second aim of this paper, existing evidence was therefore reviewed to identify factors affecting speech perception in the context of mainland China.

Methods

Search Methods

The main inclusion criterion was studies that evaluated children with prelingual HI and who used Mandarin as their first language. PubMed, Scopus, and Wiley online library were searched for eligible studies. The keywords used included [(Chinese) OR (Mandarin) OR (Putonghua)] AND [(cochlear implantation) OR (cochlear implants) OR (cochlear implant)] AND [(perception) OR (identification) OR (detection) OR (recognition) OR (comprehension)]. The search was limited to journal papers published in English and conducted in mainland China. Studies on children with other disabilities and (or) abnormal inner ear structures and/or nerve deficiency were excluded.

Results

Paper selection

The search initially yielded 468 titles (253 from PubMed, 132 from Scopus, 83 from Wiley online library) that were potentially relevant to the topics of concern. Two hundred and one papers appeared more than once in these databases, resulting in 299 duplicates that were discarded, and 169 non-duplicated records to retrieve.

After a review of the abstracts and full papers, 155 articles were further excluded as they contained information that is not relevant to the topic of concern (i.e., reports on NH children or adults, reports on post-lingual children or adults, and irrelevant study objectives). Finally, 14 articles remained for the review.

Findings

Across the 14 studies, participant demographics varied substantially and none reported effect size. Thus, the data could not be pooled for meta-analyses. These results are therefore being presented descriptively.

The trajectories in speech perception development in Mandarin-speaking children with CIs

Four out of the 14 studies tracked the development of speech recognition over time using a time-series design (X. Q. Chen et al., 2010; Y. Chen et al., 2016; Liu et al., 2015; Zheng et al., 2011). Table 1 shows detailed information and the most important reasons for biases. Outcomes were assessed in terms of (1) prelingual auditory behavior, (2) early speech identification, (3) closed-set sentence identification, and (4) open-set word recognition.

The IT-MAIS/MAIS, the MESP, and the MPSI were used in Zheng et al. (2011) and Y. Chen et al. (2016) at baseline and 3, 6, and 12 months after implantation while only the IT-MAIS and MAIS were used in X. Q. Chen et al. (2010) at the same test intervals. The LNT and MLNT were administered in Liu et al. (2015) at 6, 12, 24, 36, 48, 60, 72, and 84 months after implantation. All but Liu et al. (2015) reported outcomes in children implanted not later than 6 years of age; those in Liu et al. (2015) were implanted between 0.5 and 15.5 years of age. Not all studies provided detailed reports on subject demographics, thus it was difficult to ascertain how homogeneous the subjects were within a study and compare results across studies.

Eight out of the 14 reported on tone perception performance (see Table 4). Seven studies were cross-sectional (Y. Chen, Wong, Chen, & Xi, 2014; Han et al., 2009; A. Li, Wang, Li, Zhang, & Liu, 2014; Mao & Xu, 2016; Tao et al., 2015; Xu et al., 2011; Zhou, Huang, Chen, & Xu, 2013) and one is a review (Tan, Dowell, & Vogel, 2016). None of the tone perception tests used in these studies had been standardized, which was the major source of bias. Other sources of bias include small sample size of not more than 30 (Han et al., 2009; A. Li et al., 2014; Tao et al., 2015; Xu et al., 2011) and omitted information such as maternal education level, hearing aid use before and after implantation and interventions obtained (Zhou et al., 2013).

1. Prelingual auditory behavior

Three studies evaluated early prelingual auditory behavior during the first 12 months of CI use using the IT-MAIS/MAIS (X. Q. Chen et al., 2010; Y. Chen et al., 2016; Zheng et al., 2011).

These studies all generated similar results (see Table 2). That is, the mean scores at 3, 6, and 12 months were around 50%, 65%, and 82%, respectively. Y. Chen et al. (2016) and Zheng et al. (2011) both compared their IT-MAIS/MAIS results with those obtained in English-speaking children in Eisenberg et al. (2006); no significant differences were found. This suggested that implant recipients were able to attain similar prelingual auditory skills reaching about 80% on the IT-MAIS/MAIS by 12 months after implantation, regardless of language exposure (English versus Mandarin).

2. Early speech identification

Two studies (Y. Chen et al., 2016; Zheng et al., 2011) evaluated early speech perception within the first 12 months of CI use using the MESP (see Table 2).

Results from the two studies suggest that by six months of CI use, about 50% of children were able to achieve pattern perception (Category 2) on the LV-MESP. After six months of CI use, a small proportion of children were able to achieve spondee perception (Category 3) on the SV-MESP. After 12 months of CI use, the expectation was that more than 50% of children were able to achieve vowel and consonant perception (Category 4 and 5 respectively on the SV-MESP). Because of differences between the MESP and the English version of the Early Speech Perception test (ESP) (i.e., there were six categories in the MESP and four categories in the ESP), comparison of performance in Mandarin-speaking and English-speaking children could not be made.

3. Closed-set sentence identification

Two studies (Y. Chen et al., 2016; Zheng et al., 2011) evaluated closed-set sentence identification in quiet and in noise using the MPSI during the first year of CI use (see Table 2). Both studies showed that only a small proportion of children (10% to 20%) started to demonstrate very limited closed-set sentence identification in quiet (33% to 42%, chance=16.7%) after six months of CI use, suggesting this ability is only emerging. By 12 months of CI use, more than half of the children were able to identify on average about half of the MPSI sentences in quiet. Furthermore, closed-set sentence identification in noise emerged after 12 months of CIs. That is, about 30% to 50% of children were able to identify closed-set sentences on +10 dB S/N test condition.

4. Open-set word recognition

Only one study (Liu et al., 2015) examined open-set word recognition longitudinally using the LNT and the MLNT. Results displayed in Figure 1 show significant improvement in the first 36 months of CI use, and performance plateaued after 48 months of CI use.

5. Tone perception

Five studies used different two-alternative forced-choice tone contrast tests to evaluate tone identification (Y. Chen et al., 2014; Han et al., 2009; A. Li et al., 2014; Xu et al., 2011; Zhou et al., 2013). The demographics varied greatly across studies which included mean age at testing ranging from 2.41 to 16.5 years of age, mean age at implantation ranging from 3.1 to 6.4 years of age, and mean duration of CI use ranging from 1.3 to 4.4 years. Despite variations in these demographics and test materials, mean tone identification scores ranged from 67% to 82% in quiet were reported, which is significantly above chance level (i.e., 50%).

Only one study (Tao et al., 2015) investigated tone recognition skills in children with relatively long duration of CI use (mean=6.5 years) using a four-alternative forced-choice tone recognition test and found good performance in quiet (overall mean=81% correct, chance level=25%). Only one study (Mao & Xu, 2016) investigated Mandarin tone identification in the presence of speech-shaped noise and found a marked deficit in tone perception performance in noise; and performance was more susceptible to noise than their normal hearing peers. Tan et al. (2016) synthesized results from four studies (Han et al., 2007; Peng, Tomblin, Cheung, Lin, & Wang, 2004; Xu et al., 2004; Zhou et al., 2013) on Mandarin tone identification and production and concluded that lexical tone perception was possible by children with CIs. However, no conclusion regarding the age of implantation and duration of CI use required to achieve such a level of tone perception skills was given.

Four studies evaluated variations in perceptual abilities across the four lexical tones. A. Li et al. (2014) found tone contrasts containing Tone 4 was the easiest to identify while Zhou et al. (2013) did not find statistical differences in perception among the six tone contrasts. On the other hand, Y. Chen et al. (2014) and Mao and Xu (2016) reported that Tone 2 / Tone 3 contrast was the most difficult.

Summary

Before implantation and 3 months after implantation, most children with CIs could only be evaluated using the IT-MAIS/MAIS. After six months of CI use, about half of the children were achieving Pattern perception (i.e., Category 2 on the LV-MESP). After 12 months of implantation, around half of the children could be evaluated using the SV-MESP and the MPSI, achieving Vowel or Consonant perception (i.e, Category 4 and 5 on the SV-MESP) and +10 dB S/N test condition of the MPSI-N, suggesting substantial progress in closed-set word and sentence identification during the first year of CI use. Open-set word recognition ability evaluated using the MLNT/LNT showed steep improvement between 12 to 36 months, and performance plateaued after 48 months of CI use. However, outcomes of the MLNT/LNT were from one study; further investigations are required to verify these findings.

Although all studies about tone perception were cross-sectional and differs in participant demographic characteristics and test materials, the studies all concluded that perception of lexical tone was possible in Mandarin-speaking children with CIs. That is, children are expected to identify tones above chance level after one to three years of CI use. Overall, mean tone identification scores ranged from 67% to 82% in quiet (chance level=50%), but there are mixed findings in terms of which tone contrasts are easier to identify. Further research is required to examine tone perception in noise and long-term development of tone perception in quiet.

Table 3 summarizes speech perception developmental expectations/goals, defined as speech perception skills that at least 50% children with CIs in the previous studies were able to demonstrate at each test interval.

Factors influencing speech perception

The second aim of this review was to identify factors influencing speech perception. A total of seven studies were included (see Table 5). Three of them were longitudinal studies (X. Q. Chen et al., 2010; Y. Chen et al., 2016; Liu et al., 2015) while the rest were cross-sectional studies with sample size larger than 90 (Y. Chen et al., 2014; Y. Chen et al., 2015; Liu et al., 2013; Zhou et al., 2013). The demographics varied greatly across studies which included mean ages at testing ranging from 4.16 to 8.00 years of age, mean ages at implantation ranging from 2.67 to 3.98 years of age, and mean duration of CI use ranging from 0.00 to 4.10 years. The outcomes evaluated included tone identification in quiet, early auditory behavior, open-set word recognition in quiet, and sentence identification in quiet as well as in noise.

All seven studies reported significant effects of age at implantation on speech perception except Y. Chen et al. (2014). All seven studies found that longer duration of CI use contributed to better speech perception except Y. Chen et al. (2014). Three out of seven studies evaluated the effects of maternal education level (MEL) on speech perception (Y. Chen et al., 2014; Y. Chen et al., 2015; Y. Chen et al., 2016).

Y. Chen et al. (2014) and Y. Chen et al. (2016) reported better MEL contributed to better sentence perception in quiet and in noise. Y. Chen et al. (2015) found that higher MEL contributed to speech perception via its effects on younger age at implantation.

Four out of the seven studies (X. Q. Chen et al., 2010; Y. Chen et al., 2014; Y. Chen et al., 2015; Y. Chen et al., 2016) evaluated the effects of a hearing aid trial (HAT) before implantation on speech perception and mixed results were reported. While X. Q. Chen et al. (2010) and Y. Chen et al. (2014) found this factor significantly affected prelingual auditory skills and sentence identification in noise. Y. Chen et al. (2014), Y. Chen et al. (2015), and Y. Chen et al. (2016) failed to find an effect of this factor on tone identification in quiet, sentence identification in quiet and overall speech perception as a composite score combining results from the IT-MAIS/MAIS, the MESP, and the MPSI using principal component analysis, respectively.

Three out of the seven studies evaluated the effects of pre-implant hearing level on speech perception (Y. Chen et al., 2014; Y. Chen et al., 2015; Y. Chen et al., 2016) and mixed results were reported. Y. Chen et al. (2016) reported significant effects on speech perception during the first year of CI use while Y. Chen et al. (2014) and Y. Chen et al. (2015) did not find significant effects on speech perception in children with one to three years of CI use.

Two out of the seven studies (Y. Chen et al., 2016; Zheng et al., 2011) measured the effects of dialect exposure on prelingual auditory and early speech perception development and both found that consistent language input via CI probably enhances prelingual auditory and early speech perception development at least during the first year of CI use. However, these studies are descriptive in nature and many confounds such as age at implantation and whether the MEL have not been controlled.

Summary

The findings that age at implantation, duration of CI use, and the MEL significantly affected speech perception were consistently reported. Findings about the effects of pre-implant hearing level and a HAT before implantation on speech perception were rather inconsistent. The effect of dialect exposure on speech perception requires research that controls confounds and employs statistical comparisons.

Discussion

Tracking auditory and speech perception progress

Clinicians may use the results provided in this review to determine whether children make sufficient progress with a CI. In addition, speech perception developmental goals listed in Table 3 could be used to identify children who are progressing at a slower rate. However, Table 3 only provides general speech perception developmental goals due to limited number of studies available. If a child exhibits a delay of a particular skill at any test interval, greater attention should be devoted to develop that skill. Besides using Table 3 to ensure that foundational skills have been established before proceeding to more advanced ones, Robbin (2005) also recommended other actions that clinicians can take for children who are progressing at a slower-than-expected rate. These include confirming whether the device is working, breaking down the training into smaller steps, communicating and working with parents, considering the use of other devices that may enhance sensory inputs, and ruling out additional disabilities.

However, it is important to remember that these developmental goals were derived from a limited number of studies, ranging from one to four, and could only applied to children in mainland China. Despite similarities in findings across studies, further research is needed to account for possible idiosyncrasies and ensure trusted conclusions, such as refining these speech perception goals for children implanted at different ages. Furthermore, the studies reported in this review are limited to demonstration of early speech perception skills and no research has examined more advanced abilities such as open-set sentence recognition. Given that the CDaCI has also incorporated the English version of the Hearing in Noise Test (HINT) and its Mandarin version (MHINT, Wong, Soli, Liu, Han, & Huang, 2007) has been standardized, it will not be long before reports of these abilities become available as the children in mainland China gain experience with CI.

Tone perception

All reviewed studies reported certain levels of tone perception skills in spite of sparse pitch information provided by a CI. However, as the mean duration of CI use is fewer than 3 years in most studies and there is a lack of data on long-term tone perception performance, the level of tone recognition ability that can be achieved eventually is still unknown. Another concern is that tests used in these studies have not been standardized. The Mandarin Tone Identification Test (MTIT) (Zhu, Wong,

& Chen, 2014), with good psychometric properties, has been made available recently. Its application in CI users has yet to be reported.

Factors influencing speech perception

It was not surprising to find a younger age at implantation and a longer duration of CI use contributed to better speech perception in Mandarin-speaking children with CIs as the same effects were repeatedly reported in the English-speaking population (Geers et al., 2003). The influence of age is related to "sensitive periods" in the maturation of the auditory system (Sharma, Dorman, & Kral, 2005). Although the sensitive cutoff point for central auditory system development is still debatable, neural plasticity degrades with the increase in ages (Sharma et al., 2005; Sharma, Dorman, & Spahr, 2002). Declining neural plasticity and lack of auditory experience negatively affect central neural organization for audition and lead to unsatisfactory hearing, speech and language performance after implantation (Houston & Miyamoto, 2010; Sarant, Blamey, Dowell, Clark, & Gibson, 2000). Considering the importance of early implantation on speech perception, Y. Chen et al. (2015) and W. Li, Dai, Li, Chen, and Jiang (2016) examined variables that contributed to early implantation. They found living in a rural community, financial burden and communication barriers negatively affected the age at CI, while universal newborn hearing screening and higher maternal education level positively impacted the age at CI. Thus, to ensure early implantation, appropriate infrastructure must be in place.

Better MEL significantly contributed to early speech perception over the first year of CI use (Y. Chen et al., 2016). This highlighted the important role of mothers. Y. Chen et al. (2015) speculated that the relationship between the MEL and speech perception is not straightforward, probably being mediated by the socioeconomic status of the family and mothers' interactions with their children. First, mothers with higher MEL are more likely to have higher socioeconomic status which helps to finance appropriate audiological and rehabilitative services. Second, mothers with higher MEL tend to be less directive, talk more and use more varied vocabulary when interacting with their children. Mothers with lower MEL, on the other hand, may have difficulties applying techniques learned in aural rehabilitation sessions to enhance speech perception development at home (Hoff & Tian, 2005). Therefore, clinicians should assist these mothers to enhance verbal interactions with their children.

Findings about the effects of pre-implant hearing level and a HAT before implantation on speech perception were rather inconsistent. This may be explained by two reasons. First, these factors may only affect some specific speech perception skills. For example, Y. Chen et al. (2014) reported that a HAT significantly affected sentence perception in noise but not tone perception in quiet or sentence perception in quiet. Second, the effects of these factors may change with increased CI use. Y. Chen et al. (2016) reported significant effects of pre-implant hearing level on speech perception during the first year of CI use, but the effects of this factor seemed to diminish as the same participants gained more experience with CIs (Y. Chen et al., 2015). Longitudinal studies are needed to verify these speculations.

Other factors that have not been examined might also impact post-implantation speech perception development in Mandarin-speaking children. First, as mentioned above, it is not uncommon that grandparents act as main caregivers in mainland China. These grandparents may be less educated and often are more directive and interact less frequently with their grandchildren. Second, a large proportion of children with CIs did not wear HA on the nonimplant ear perhaps because parents and some clinicians have the misconceptions that HAs may interfere speech perception especially during the first year use of CIs. However, Moberly, Lowenstein, and Nittrouer (2016) found that early bimodal stimulation could enhance language acquisition. Reference to evidence in English-speaking children and localized research would clarify this concern and promote the use of a contralateral HA in mainland China. Third, the exclusive use of oral mode of communication after implantation in mainland China should be examined for effectiveness among the late-implant population (i.e., those implanted after 5 years of age) or children with slow progress. Last but not least, considering the diversity of dialects in mainland China, the effects of dialect exposure on speech perception is worth further research.

Conclusions

This review helps to establish developmental goals among Mandarin-speaking children with CIs. Clinicians may use these goals to determine whether children have made appropriate progress and whether increased attention should be given to address particular speech perception issues. Tools for measuring more advanced speech perception skills are needed.

After one to three years of CI use, children are expected to identify lexical tone above chance level. Further studies are required to examine long-term tone perception development and tone perception in noise.

Prevailing evidence suggests that a younger age at implantation, a longer duration of CI use, and a higher MEL contribute to better speech perception skills. Studies on the effects of pre-implant hearing level and a HAT generated mixed results. Therefore, these effects need to be explored further with larger samples. In addition, factors such as grandparent involvement, the use of HA on the nonimplant ear and the exposure of dialects are worth considerations.

Declaration of interest: the authors report no conflicts of interest.

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Table 1. Summary of study characteristics and results on the trajectories of speech perception development in Mandarin-speaking children with CIs. M=mean, R=range, SD=standard deviation

Study	Participants demographics	Outcome measures	Overall results	Comments
X. Q. Chen et al. (2010)	N=259 Age at implantation (years): (M=1.8, R=0.7-3. 0). Test intervals: before CI, 1, 2, 3, 6, and 12 months after CI.	IT-MAIS/MAIS	The mean scores for the auditory skills improved significantly over time.	Omitted information (such as the presence of other impairments and dialect exposure)
Zheng et al. (2011)	N=39 Age at implantation: 1-2 years (n=4), 2-3 years (n=12), 3-4 years (n=12), 4-6 years (n=12) Test intervals: before CI, 3, 6, and 12 months after CI	IT-MAIS/MAIS MESP MPSI	Early speech perception results comparable to those of English-speaking counterparts Both Mandarin dialect exposure and the duration of pre-implant hearing aid use significantly impacted measures of early speech perception among children in Sichuan province.	Small sample size. Only descriptive data presented

Liu et al. (2015)	N=105 Age at implantation (years): (M=3.1, R=0.9-15.5, SD=2.3). Test intervals: 6, 12, 24, 36, 48, 60, 72, and 84 months after CI.	LNT, MLNT	Even after 6 years of CI use, there was a significant deficit in open-set word-recognition performance, compared with their normal hearing peers. Age at implantation had significant effects on open-set word-recognition performance.	Floor and ceiling effects when using the LNT/MLNT before 12 months of CI use and after 48 months of CI use, respectively.
Y. Chen, et al. (2016)	N=80 Age at implantation (years): (M=2.6, R=0.9-5.0, SD=1.0) Pure-tone threshold average (dB HL): (M=105, R=81-115, SD=9.1) Maternal education level (years): (M=9.7, R=0-19, SD=3.6) Test intervals: before CI, 3, 6, and 12 months after CI	IT-MAIS/MAIS MESP MPSI	Early speech perception results comparable to those of English-speaking counterparts Better pre-implant hearing level, younger age at implantation, and higher maternal education level were significantly associated with better early speech perception during the first year of CI use	Uncertain how similar the MESP and MPSI are to their English versions, therefore, whether direct comparisons could be made

Table 2. Results of the IT-MAIS/MAIS, the MESP, and the MPSI from X. Q. Chen et al. (2010), Zheng et al. (2011) and Y. Chen et al. (2016). "-" represents no data reported. The rows labeled "proportion" show the percentage of participants who could be tested with the MESP or the MPSI at each test interval. The rows labeled "mean category" report the mean category score obtained up to a maximum of 4 categories for the LV-MESP and 6 categories for the SV-MESP. The rows labeled "mean test condition" report the mean test condition achieved for the MPSI (i.e., scores significantly higher than chance).

		Pre-implant	**Post-implant**		
Study		**Baseline**	**3 months**	**6 months**	**12 months**
X. Q. Chen et al. (2010)					
IT-MAIS/MAIS	Mean score	25%	52%	72%	83%
	Range	3-50%	26-70%	57-97%	63-100%
	SD	-	-	-	-
Zheng et al. (2011)					
IT-MAIS/ MAIS	Mean score	30%	52%	68%	82%
	Range	-	-	-	-
	SD	23.6%	24.4%	19.4%	13.7%
LV-MESP	Proportion	43.6%	-	61.5%	30.8%
	Mean category	1.6	-	2.2	2.3
SV-MESP	Proportion	0	-	10.3%	53.8%
	Mean category	-	-	3	4.8
MPSI-Q	Proportion	0	-	10.3%	33.9%
	Mean score	-	-	33%	66%
MPSI-N	Proportion	-	-	-	30.8%
	Mean test condition	-	-	-	+10 dB S/N
Y. Chen et al. (2016)					
IT-MAIS/ MAIS	Mean score	16%	46%	63%	80%
	Range	0-57%	10-79%	14-90%	53-100%
	SD	21%	19%	22%	15%

LV-MESP	Proportion	21.1%	50%	55.9%	40%
	Mean category	1.4	1.8	2.1	2.8
SV-MESP	Proportion	0	11.1%	32.4%	60%
	Mean category	-	4.8	4.0	4.7
MPSI-Q	Proportion	0	8.3%	20.6%	56.7%
	Mean score	-	61%	42%	60%
MPSI-N	Proportion	-	-	-	56.7%
	Mean test condition	-	-	-	+10 dB S/N

” represents time post-implant that a child could demonstrate the skill.

Skills	3 months	6 months	12 months	24 months	48 months
Major improvement in prelingual auditory skills					
Able to identify some closed-set words					
Emerging ability to identify closed-set vowels and consonants					
Able to derive meaning from closed-set sentences in quiet and in noise					

Emerging ability to identify lexical tones above chance level

Major improvement in open-set word recognition

High level of open-set word recognition skill

Table 4. Summary of study characteristics and results from literatures regarding tone perception. M=mean, R=range, SD=standard deviation

Study	Participant demographics	Outcome Measured	Overall results
Han et al. (2009)	N=20 Age at test (years): (M=7.6, R=3.5-16.5, SD=4.1) Age at implantation (years): (M=5.21, R=1.3-13.5,SD=3.8) Duration of CI use (years): (M=2.4,R=0.6-4.2, SD=1.2)	A two-alternative, forced-choice tone contrast (identification) test	M=74%-82%, chance=50%
Xu et al. (2011)	N=25 Age at test (years): (M =9.5, R=2.1-21.5, SD=5.4) Age at implantation (years): (M=6.4, SD=5.2). CI use (years): (M=3.1, SD=2.5)	A two-alternative forced-choice tone contrast (identification) test	M=71%, R=50 to 97% (chance=50%).

Zhou et al. (2013)	N=107 Age at test (years): (R=2.4-16.2) Age at implantation (years): (M=4.0, R=1.1-13.0, SD=2.7) Duration of CI use (years): (M=1.3, R=0.1-4.9, SD=1.0)	A two-alternative forced-choice tone contrast (identification) test	Performance of the CI group ranged from chance to perfect (M=67%, SD=13%, chance=50%). No statistical differences were found between the performance of the six contrasts
Y. Chen et al. (2014)	N=96 Age at test (years): (M=4.5, R=2.4-7.0, SD=1.0) Age at implantation (years): (M=2.7, R=0.7-5, SD=1.0) Duration of CI use (years): (M=1.6, R=0.8-4.4, SD=0.7)	Tone perception category in the MESP- a two-alternative forced-choice tone contrast (identification) test	M=77% (SD=13%; chance=50%). Tone 2/Tone 3 was the most difficult tone contrast to identify
A. Li et al. (2014)	N=20 Age at test (years): (M=8.6, R=6.0-11.1) Age at implantation (years): (M=4.1, R=2.0-6.8) Duration of CI use (years): (M=4.4, R=3.7-6.6)	A two-alternative forced-choice tone contrast (identification) test	M=72%, R=54%-83%). Significant higher scores were found with the tone pairs that contained tone 4
Tao et al. (2015)	N=21 Age at test (years): (M=10.8, R=6-16) Age at implantation (years): (M=4.3, R=2-12) Duration of CI use (years): (M=6.5, R=2-11)	A four-alternative, forced-choice tone recognition test	M=81%, chance=25%

Mao et al. (2016*)*	N=66 Age at test (years): (M=5.3, R=2.13-17.20, SD=3.4) Age at implantation (years): (M=3.0, R=0.6-16.5, SD=3.1) Duration of CI use (years): (M=6.5, R=0.2-8.5, SD=2.0)	A two-alternative, forced-choice tone contrast (identification) test Test condition: quiet, +12, +6, 0, and -6 dB S/N.	Children with CIs exhibited a marked deficit in tone identification in noise and were more susceptible to noise than their NH peers.

Table 5. Summary of study characteristics and results from the literature regarding factors influencing speech perception (Note: AT=age at testing, DCI= duration of CI use, AI=age at implantation, MEL=maternal education level, HL=pre-implant hearing level, HAT= a hearing aid trial).

Study	**Outcome Measured**	**Participant demographics M=mean, R=range, SD=standard deviation**	**AT**	**DCI**	**AI**	**MEL**	**HL**	**HAT**
X.Q. Chen et al. (2010)	Prelingual auditory development	N=259 Age at implantation (years): (M=1.8, R=0.7-3.0). Test intervals: before CI, 1, 2, 3, 6, and 12 months after CI.		✓*	✓*			✓*
Liu et al. (2015)	Open-set word recognition	N=230 Age at test (years): (M=8.0, R=2.8-17.5, SD=3.4) Duration of CI use (years): (M=4.1, R=1.1-11.8, SD=2.7) Age at implantation (years): (M=3.9, R=0.9-16.0, SD=3.0)		✓*	✓*			
Zhou et al. (2013)*	Lexical tone perception	N=110 Age at test (years): (R=2.4-16.2) Age at implantation (years): (M=4.0,R=1.1- 13.0, SD=2.7)	✓	✓*	✓*			

Y. Chen et al. (2014)	Lexical tone perception	N=96 Age at test (years): (M=4.5, R=2.4-7.0, SD=1.0) Age at implantation (years): (M=2.7, R=0.7-5.0, SD=1.0) Duration of CI use (years): (M=1.6, R=0.8-4.4,SD=0.7) Maternal education level (M=10.6, R=0-19, SD=3.6)		✓	✓	✓	✓	✓
	Sentence perception in quiet			✓*	✓	✓*	✓	✓
	Sentence perception in noise			✓*	✓	✓*	✓*	✓*
Liu et al. (2015)	Open-set word recognition	N=105 Age at implantation (years): (M=3.1, R=0.9-15.5, SD=2.3). Test intervals: 6, 12, 24, 36, 48, 60, 72, 84 months after CI.		✓*	✓*			
Y. Chen et al. (2015)	Overall speech perception (combining results from the IT-MAIS/MAIS, the MESP, and the MPSI to generate a single score using the principal component analysis)	N=115 Age at test (years): (M=4.2, R=2.5-7.1, SD=1.1) Age at implantation (years): (M=2.7, R=0.7-5.0, SD=1.1) Duration of CI use (years): (M=1.4, R=0.8-3.2, SD=0.7)	✓*		✓*	✓*	✓	✓

Y. Chen et al. (2016)*	Overall speech perception (combining results from the IT-MAIS/MAIS, the MESP, and the MPSI to generate a single score using the principal component analysis)	N=80 Age at implantation (years): (M=2.6, R=0.9-5.0, SD=1.0) Pre-implant hearing level (dB) : (M=105, R=81-115, SD=9.10) Maternal education level (years): (M=9.7, R=0-19, SD=3.6) Test intervals: before CI, 3, 6, and 12 months after CI.	✓*	✓*	✓*	✓

“✓” factors examined in the study but not significantly affected speech perception. “✓*” factors significantly affected speech perception. *Zhou et al. (2013) also examined several other factors besides the age at testing, age at implantation, and duration of CI use. These factors are family variables (family size and household income), cochlear implant variables (implant type, processor type, and speech processing strategy), and educational variables (communication mode and duration of speech therapy). However, none of these factors significantly affected tone perception performance except for age at implantation and duration of CI use.
* Y. Chen et al. (2015) and Y. Chen et al. (2016) shared some participants but they were sampled at different durations of CI use. Participants from Y. Chen et al. (2016) had been using CIs for no more than one year while participants from Y. Chen et al. (2015) had been using CIs for more than one year.