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REVIEW ARTICLE

Performance of hearing skills in children with auditory neuropathy spectrum disorder using cochlear implant: a systematic review^{☆,☆☆}



Nayara Freitas Fernandes^{a,b,*}, Marina Morettin^{a,b},
Elisabete Honda Yamaguti^{a,c}, Orozimbo Alves Costa^{b,d},
Maria Cecilia Bevilacqua^{b,c,e,1}

^a Department of Sciences, Faculdade de Odontologia de Bauru, Universidade de São Paulo (FOB - USP), Bauru, SP, Brazil

^b Department of Phonoaudiology, Universidade de São Paulo (USP), Bauru, SP, Brazil

^c Department of Phonoaudiology, Hospital for Rehabilitation of Craniofacial Anomalies, Universidade de São Paulo (HRAC - USP), Bauru, SP, Brazil

^d Division of Otology, Hospital for Rehabilitation of Craniofacial Anomalies, Universidade de São Paulo (HRAC - USP), Bauru, SP, Brazil

^e Division of Audiology, Hospital for Rehabilitation of Craniofacial Anomalies, Universidade de São Paulo (HRAC - USP), Bauru, SP, Brazil

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KEYWORDS

Evaluation;
Child;
Cochlear implants;
Hearing loss;
Speech perception

Abstract

Introduction: Currently, there are no doubts about the benefits of cochlear implants for the development of children with severe or profound hearing loss. However, there is still no consensus among researchers and professionals regarding the benefits for the improvement of hearing skills in children with auditory neuropathy spectrum disorder using cochlear implants.

Objective: Review the available evidence in the literature to answer the following: "What is the performance of hearing skills in children with auditory neuropathy spectrum disorder using cochlear implants?"

Methods: Systematic review of the literature through electronic database consultation, considering publications in the period 2002–2013.

Results: Twenty-two studies met the criteria and were included in the systematic review.

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^{☆☆} Institution: Audiological Research Center, Cochlear Implant Section, Hospital for Rehabilitation of Craniofacial Anomalies, Odontology School, Universidade de São Paulo, Bauru, SP, Brazil.

* Corresponding author.

E-mail: nayara_freitas.fernandes@yahoo.com.br (N.F. Fernandes).

¹ In memoriam.

PALAVRAS-CHAVE

Avaliação;
Criança;
Implante coclear;
Perda auditiva;
Percepção da fala

Conclusion: The analyzed studies demonstrated that after cochlear implant surgery, individuals with auditory neuropathy spectrum disorder improved their performance of hearing skills and had similar performance to that of children with sensorineural hearing loss using cochlear implant.

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Resultados do desempenho das habilidades auditivas em crianças com o espectro da neuropatia auditiva usuárias de implante coclear: revisão sistemática

Resumo

Introdução: Atualmente não restam dúvidas quanto aos benefícios do uso do implante coclear no desenvolvimento da população infantil com perda auditiva de grau severo e/ou profundo. Entretanto, ainda não há um consenso entre pesquisadores e profissionais sobre os seus benefícios para a melhora das habilidades auditivas em crianças com o espectro da neuropatia auditiva usuárias de implante coclear.

Objetivo: Revisar a evidência disponível na literatura para responder ao questionamento: "Quais os resultados do desempenho das habilidades auditivas em crianças com o espectro da neuropatia auditiva usuárias de implante coclear?"

Método: Revisão sistemática da literatura, a partir da consulta de bases de dados eletrônicas, considerando publicações no período de 2002 a 2013.

Resultados: Vinte e dois estudos contemplaram os critérios e foram incluídos na revisão sistemática.

Conclusão: Os estudos analisados demonstraram que, após a cirurgia de IC, os indivíduos com o espectro da neuropatia auditiva melhoraram o desempenho das habilidades auditivas e apresentaram desempenho semelhante ao de crianças com perda auditiva sensorineural usuárias de implante coclear.

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Introduction

The development of the skill to perceive speech sounds by an individual with auditory neuropathy spectrum disorder (ANSD) is challenging for all professionals involved in the field of education and clinical audiology, due to changes in the conduction of the auditory stimulus.

The literature defines ANSD as a change in neural synchrony, characterized by an auditory behavior in which the function of outer hair cells (OHC) is shown to be preserved, while the afferent neural transmission is altered.¹ This hearing impairment can significantly affect speech perception and the development of hearing and language abilities.

The indication of cochlear implant (CI) in this clinical group is based on the ability of the device to partially replace the functions of the auditory sensory cells and directly stimulate the auditory nerve, benefiting neural synchrony and thus contributing to the development of hearing skills.²⁻⁷

The studies reviewed suggest that the benefits of CI use in children with ANSD, particularly with respect to language acquisition and development of hearing skills, are related to the period of use of this device, the existence of the phonoaudiological rehabilitation process, time of diagnosis,

and child's age. However, there is no consensus among studies with respect to how and when the child achieves good development, and on the detailed outcome of the performance of hearing skills in children with ANSD, specifically the skills of hearing detection, discrimination, recognition, and understanding;^{8,9} rather, the results of the studies are presented more generally.

Thus, this study aimed to review the available scientific evidence in the literature to identify studies on the performance of hearing skills in children with ANSD using CI.

Methods

To achieve the objective of this study, the following question was proposed: "What is the performance of hearing skills in children with ANSD using CI?"

During the literature search, the search strategy combined six descriptors ("cochlear implant," "hearing," "hearing loss," "child(ren)," "speech perception," and "speech intelligibility") indexed in DeCS (Health Sciences Descriptors), and two descriptors ("auditory neuropathy" and "auditory neuropathy spectrum disorder") not indexed in DeCS, using various combinations of these descriptors in

Portuguese and English in order to include more articles, employing at least two keywords in all groups.

Publications issued in the period 2002–2013 were considered, and the last manual search through electronic databases occurred in November 2013. In this review, the following sources were consulted: PubMed, SciELO, Cochrane Library, LILACS, Embase, Institute for Scientific Information (ISI), MEDLINE, ScienceDirect, the annals of national congresses, and the following digital information databases: Digital Dissertation Abstracts, Brazilian Digital Library of Theses and Dissertations, and Digital Library of Theses and Dissertations of USP.

The selection of articles followed inclusion criteria based on issues related to the objective of this work. The adopted criteria were

- Participants – children with ANSD using CI.
- Intervention – standardized tests in order to evaluate the hearing performance of ANSD/CI children.
- Measured outcomes – results expressed in percentage of correct answers on perception and speech intelligibility tests, results expressed through scales of hearing skills development.
- Types of studies – studies published in English, Spanish, or Portuguese and classified according to the criteria proposed by the American Speech-Language-Hearing Association (ASHA).

Studies with groups of pre-lingual hearing impaired patients who underwent surgery in adolescence or adulthood; studies with groups of adults with post-lingual hearing loss; repeated scientific evidence, or with a different theme; literature reviews, abstracts, case reports, and articles which did not meet the inclusion criteria were excluded.

The selection of studies was conducted in three stages and guided by the above criteria. In the first stage, two reviewers selected all identified titles, selecting the articles that met the inclusion criteria. Then began the second stage, in which the data contained in the histories of hearing skills performance of children with ANSD using CI were reviewed. In cases in which the title or the body of abstract left room for doubt, the texts were collected in full (third stage) in order to assess their relevance, and then were analyzed.

In total, 4169 titles, with or without abstracts, were identified in all databases. In a pre-selection of these citations, based on reading the titles and abstracts of all studies found in the electronic search, 4145 were excluded due to: repetition, 3525; excluded by theme, 268; excluded by language, 23; literature review, one; abstracts, 395; and case reports, nine. For complete reading, 24 articles were selected.

After reading the 24 texts, six articles were excluded due to: studies in which the population's age did not fit the selection criteria, two; studies which did not use any speech perception test, two; and studies which were clinical case discussions, two.

At the end, 18 articles^{10–27} and two dissertations^{28,29} met the inclusion criteria. Of those studies included in this review, five were non-randomized controlled trials of high quality, five were characterized as randomized controlled trials of low quality, and ten were clinical outcome studies.

Results and discussion

Regarding the performance of hearing skills in the ANSD/CI population, all studies reported significant hearing improvement in speech perception skills, i.e., in hearing discrimination, pure tone detection thresholds, and recognition of words and sentences; and three studies^{17,28,29} reported improvement in sentence understanding after electrical stimulation of the auditory nerve through the use of CI.

Among the studies reviewed, 14 compared the speech perception in children with ANSD versus children with sensorineural hearing loss, both CI users.^{10–12,14,16–20,22–24,28,29} Of these 14 studies, 13 concluded that ANSD/CI children developed hearing skills similar to those of the children with sensorineural hearing loss using CI, showing similar results in speech perception tests, with no significant difference. Only in one study¹⁶ did the results show that children with sensorineural hearing loss/CI performed significantly better ($p=0.02$) compared to the three groups of children with ANSD (CI users, hearing aids [HA] users, and CI + HA users), that is, no statistically significant difference among the results of speech perception in groups of children with ANSD was found. The authors concluded that CI offers the possibility of speech perception to subjects with ANSD; however, some of these individuals (i.e., with ANSD) can be benefited through the use of HA.

In one study,²³ the authors reported that children with ANSD using HA were able to achieve a global discourse comparable with the results of speech perception in children with ANSD/CI.

Another study²⁴ showed that children with ANSD with cognitive impairment or alteration of associated development had worse outcomes when compared to children with ANSD using HA without other associated disabilities, and compared to children with sensorineural hearing loss using HA.

In one study,¹⁸ the authors reported that the performance of speech perception in ANSD/CI children may be similar to that of children with sensorineural hearing loss using HA, or in some cases this group can present extremely poor speech perception results. This fact may be related to the exact location of the alterations responsible for the ANSD,^{30,5} that is, it will depend on the location of the lesion: failure of the function of IHCs (inner hair cells) dysfunction of the synaptic junction between these cells and the fibers of cranial nerve VIII; dysfunction of the fibers of cranial nerve VIII; functional biochemical impairment of neurotransmitters or prevention of their release; or a combination of the aforementioned.^{30–34}

Thus, the study of the diagnostic topology of ANSD would facilitate a better understanding of the physiological aspects related to speech perception performance in this population. Therefore, the proper objective method for this analysis would be electrocochleography, which evaluates the cochlear function and the function of cranial nerve VIII. However, there is little information in the literature on the clinical application of this procedure in cases of ANSD.³⁵ In the present review, two of the studies analyzed^{20,25} evaluated the auditory nerve in children with ANSD through MRI and high-resolution CT. One study²⁰ demonstrated that children with ANSD may show an auditory nerve deficit associated with abnormalities in the inner

Table 1 Results in the recognition of monosyllabic words test, Infant-Toddler Meaningful Auditory Integration Scale (IT-MAIS), Glendonald Auditory Screening Procedure (GASP), and the Hearing In Noise Test (HINT).

Authors (year)	Journal (country) and sample number	Inventory		Speech perception test					
		IT-MAIS/MAIS		GASP (word recognition)		Monosyllabic words (Open Set)		HINT	
		ANSD	SNHL	ANSD	SNHL	ANSD	SNHL	ANSD	SNHL
Breneman et al. (2012)	J Am Acad Audiol (United States). 70 children (35 ANSD and 35 sensorineural, both CI users), Mean period of CI use: five years	98%	98%	50–100%	58–63%	83%	77%	–	–
Teagle et al. (2010)	Ear Hear (United States). 140 ANSD/CI children.	Pre-CI values: 5–63%. Post-CI values: 48% (1 year of CI use) to 98% (3 years of CI use).	–	–	–	–	–	–	–
Kim et al. (2011)	Acta Otolaryngol. (South Korea). Six children with ANSD and four with sensorineural hearing loss, both CI users.	–	–	–	–	4 years of CI use – 95% 5 years of CI use – 95% 6 years of CI use – 95%	4 years of CI use – 73% 5 years of CI use – 70% 6 years of CI use – 80%	–	–
Schramm et al. (2010)	Cochlear Implants Int. (Canada). 16 children with ANSD and 89 with sensorineural hearing loss, both CI users. Mean time of CI use: 1 year 6 months	Pre-CI values: 2.5–15% Post-CI values: 75–85%	Pre-CI values: 2.5–15% Post-CI values: 75–85%	66–75%	66–75%	–	–	76 dB in a quiet condition	78.9 dB in a quiet condition

Table 1 (Continued)

Authors (year)	Journal (country) and sample number	Inventory		Speech perception test					
		IT-MAIS/MAIS		GASP (word recognition)		Monosyllabic words (Open Set)		HINT	
		ANSD	SNHL	ANSD	SNHL	ANSD	SNHL	ANSD	SNHL
Chisholm et al. (2010)	Cochlear Implants Int. (Australia). 5 ANSD/CI children.	Pre-CI values: 6.25–18.75% Post-CI values: 37.5–87.5% (1 year of use); 57.5–97.5% (2 years of CI use); 82.5–97.5% (5 years of CI use).	–	75% (2 years of CI use)	–	–	–	–	–
Rance et al. (2008)	Otol Neurotol. (Australia). Seven children with ANSD, uni- ($n = 4$) or bilateral ($n = 3$) CI users; ten children with bilateral ANSD using HA; three ANSD/CI children and contralateral HA users; 37 children with sensorineural hearing loss using CI.	–	–	–	–	HA users: 24.8–55.1%. IC users: 20.6–59.6%. Both with 5 years of CI use	53–83.1% 5 years of CI use	–	–
Peterson et al. (2003)	J. Am. Acad. Audiol. (United States). Ten children with ANSD; ten children with sensorineural hearing loss, both CI users.	Pre-CI: 0–50% Post-CI: 70% (1 year of CI use)–100% (1 year 6 months of CI use)	Pre-CI: 0–55% Post-CI: 65% (1 year of CI use) to 100% (2 years of CI use)	83% (3 years of CI use) to 100% (1 year of CI use) Sentence understanding 70–100% (3 years of CI use)	83% (2 years of CI use) to 100% (1 year of CI use) Sentence understanding 50–90% (2 years of CI use)	100% (1 year of CI use)	96–100% (2 years of CI use)	Result of only one child (3 years of CI use). Quiet condition 80 dB Noise condition (20 S/R) 45 dB	Result of only one child (5 years of CI use) Quiet condition 80 dB. Not performed in noise condition

Table 1 (Continued)

Authors (year)	Journal (country) and sample number	Inventory		Speech perception test					
		IT-MAIS/MAIS		GASP (word recognition)		Monosyllabic words (Open Set)		HINT	
		ANSD	SNHL	ANSD	SNHL	ANSD	SNHL	ANSD	SNHL
Jeong et al. (2007)	Acta Otolaryngol Suppl. (South Korea). Nine children with ANSD, 12 children with sensorineural hearing loss, both CI users	-	-	-	-	Sentence recognition 5% (6 months of CI use) to 100% (3 years of CI use)	Sentence recognition 20% (6 months of CI use) to 90% (3 years of CI use)	-	-
Pelosi et al. (2012)	Otology & Neurotology (United States). 13 ANSD/CI children (Seven bilateral and six unilateral CI users). Mean time of CI use: 3 years 6 months	Pre-CI: 13–21% Post-CI: 45–100%	-	-	-	-	-	67 dB–98 dB Noise condition.	-
Cardon et al. (2013)	International Journal of Audiology (United States). 24 children with ANSD, 11 children with sensorineural hearing loss, both CI users. Mean time of CI use: 3 years 6 months	Pre-CI: 13–21% Post-CI: 45–100%	Pre-CI: 13–21% Post-CI: 100%	-	-	-	-	-	-
Pelosi et al. (2013)	Otolaryngology – Head and Neck Surgery (United States). 16 children with ANSD/unilateral CI users, and ten children with ANSD/using bilateral HA.	Pre-CI: 13% Post-CI: 0–65% (4 years 3 months of CI use) Post-HA values: 0–72% (3 years 6 months of CI use)	-	-	-	-	-	CI users: 63–98 dB Noise condition (4 years 3 months of use) HA users: 86–98 dB Noise condition (3 years 6 months)	-

Table 1 (Continued)

Authors (year)	Journal (country) and sample number	Inventory		Speech perception test					
		IT-MAIS/MAIS		GASP (word recognition)		Monosyllabic words (Open Set)		HINT	
		ANSD	SNHL	ANSD	SNHL	ANSD	SNHL	ANSD	SNHL
Budenz et al. (2013)	Otol Neurotol (United States). 17 children with ANSD and 17 children with sensorineural hearing loss, both CI users. Mean time of CI use: seven years	Pre-CI values: mean 0% Post-CI values: 92%	Pre-CI values: mean 3% Post-CI values: 77%	> 25% Sentence understand- ing 25%	> 25% Sentence understand- ing 25%	-	-	-	-
Jeong et al. (2013)	Acta Otolaryngologica (South Korea). 15 children with ANSD/CI. Mean time of CI use: 5 years 6 months	Pre-CI values: 2.5–10%. Post-CI values: 100%	-	-	-	-	-	-	-
Alvarenga et al. (2013)	Inter J of Pedia Otorhi (Brazil). 14 ANSD/CI children.	-	-	73–100% (3 years 5 months of use)	-	-	-	-	-
Carvalho et al. (2011)	Braz J Otorhinolaryngol (Brasil). 18 ANSD/CI children. Mean time of CI use: 3 years 5 months	-	-	Speech recognition in closed set 61% Speech recognition in open set 33%	Speech recognition in closed set 71% Speech recognition in open set 29%	-	-	-	-

Table 1 (Continued)

Authors (year)	Journal (country) and sample number	Inventory		Speech perception test					
		IT-MAIS/MAIS		GASP (word recognition)		Monosyllabic words (Open Set)		HINT	
		ANSD	SNHL	ANSD	SNHL	ANSD	SNHL	ANSD	SNHL
Fernandes (2013)	Dissertation (Brazil). Ten children with sensorineural hearing loss and 15 children with ANSD, both groups CI users. Mean time of CI use: seven years	-	-	-	-	-	-	Results of 1st evaluation: Quiet condition 60.7 dB Noise condition (S/R) 7.1 dB Results of 2nd Evaluation: quiet condition 57.4 dB Noise condition (S/R) 2.1 dB Quiet condition 58.2 dB Noise condition (S/R) 7.6 dB (6 years of use) Results of 14 children with ANSD	Results of 1st evaluation: quiet condition 57.1 dB Noise condition (S/R) 7.9 dB Results of 2nd evaluation: quiet condition 54.1 dB Noise condition (S/R) 2.8 dB Quiet condition 58.4 dB Noise condition (S/R) 7.7 dB (6 years of use) Results of 12 children sensorineu- ral hearing loss
Yamaguti (2013)	Dissertation (Brazil). 48 ANSD/CI children and 12 children with sensorineural hearing loss	Pre-CI values: 21.8% Post-CI values: 96.7% (4 years 2 months of CI use)	-	-	-	-	-		

-, Instruments not used.

ANSD, auditory neuropathy spectrum disorder; SNHL, sensorineural hearing loss.

ear, with worse outcomes in speech perception after CI use. In another study,¹⁹ the authors reported that children with ANSD with a normal cochlear nerve preoperatively demonstrated excellent results in tests of speech perception after CI use. Radiological findings of a narrow or defective nerve correlated with poor speech perception after CI use, demonstrating that preoperative radiological studies, including computed tomography and magnetic resonance imaging, were considered predictive and reliable tools with respect to the speech perception of children with ANSD after CI use.

It may be noted that, for the evaluation of hearing skills, the selected studies used a wide variety of instruments, including speech perception tests and inventories answered by the patients' parents, or a combination of both. Thus, four studies applied the recognition of monosyllabic words test,^{12,16,19,26} six studies applied the Infant-Toddler Meaningful Auditory Integration Scale (IT-MAIS),^{13,21-23,25,29} three studies employed IT-MAIS and the Glendonald Auditory Screening Procedure (GASP),^{14,15,24} two studies applied the IT-MAIS, the GASP, and the recognition of monosyllabic words test,^{10,17} three studies^{14,17,21} used, in addition to the speech perception tests cited, the Hearing in Noise Test for Children (HINT-C), and two studies^{28,29} used the Hearing in Noise Test (HINT) translated into Portuguese.³⁶ The results of these studies are shown in Table 1. Note that Table 1 presents the results of the assessments (speech perception tests and inventories) related to children with ANSD and also to children with sensorineural hearing loss, both users of CI.

It was observed that, regarding the evaluation by parents of their children's hearing development assessed by the IT-MAIS questionnaire, before surgery the results ranged from 0% to 65% for the group of children with ANSD. After surgery, the results were analyzed according to the duration of CI use. Thus, the results of IT-MAIS ranged from 37.5% (one year of CI use) to 100% (one year and six months of CI use). When compared to the results of children with sensorineural hearing loss, it was found that the pre-surgical results of the IT-MAIS varied between 0% and 55%; and the postoperative results ranged from 65% (one year of CI use) to 100% (two years of CI use).^{10,13-15,17,21-25}

Seven studies^{10,12-16,19} indicated that ANSD/CI children were benefited in the acquisition of hearing skills: sound detection, discrimination, and recognition of words and sentences, with good results with a minimum of six months and a maximum of six years of CI use. As to the skill of hearing understanding, three studies^{17,28,29} demonstrated that ANSD/CI children achieved this skill by approximately three years of CI use.

Given the interest in knowing more specifically the performance outcomes of hearing skills in children with ANSD using CI, Table 2 condenses the hearing recognition and understanding results and the period of use of the device, comparing ANSD vs. sensorineural hearing loss in the groups of children using CI. Therefore, we tried to relate the results of the development of hearing skills over the time that the device was used as a way to describe how the evolution of children with ANSD occurs after the CI surgery. It is noteworthy that the data of the surveyed studies did not show in their, the evaluation of all hearing skills, all the relationships between the measured skill and the time that the CI had been in use in both populations (ANSD vs.

sensorineural hearing loss). It is important to publish the results of evaluations according to the length of CI use.

In general, it is worth noting that despite the methodological variables used, we observed that the majority of ANSD/CI children were able to achieve complex levels of hearing skills, i.e., they obtained good performance in the evaluation of speech recognition, in an open set condition.

Other instruments of speech perception used less frequently in these studies were: the auditory questionnaire LittleEARS, the early perception speech (ESP) test, speech recognition in quiet and noise condition test (i.e., Speech Perception Junior test (CRISP Jr.), Multisyllabic Lexical Neighborhood Test (MLNT), Pre-school Language Scale 4 (PLS-4), Phonetically Balanced Kindergarten (PBK), Melbourne Speech Perception Score, Northwestern University Children's Perception of Speech (NU-CHIPS), Lexical Neighborhood Test (LNT)), and a version of the AzBio Sentence Test adapted for children. The tests, in open and closed sets, were applied in a soundproof booth with live voice or recorded stimuli. The Hearing in Noise Test sentences for Children (HINT-C).^{10,11,13-15,18,20-25} The results of these instruments were not included in this study, since they are more often used in other countries.

Also, in relation to the procedures used in the evaluation of hearing skills, three studies^{14,17,21} used the HINT-C, but only one study¹⁷ measured the word recognition in noisy conditions (signal/noise ratio [S/N] + 20 dB), and two studies^{28,29} used the HINT translated into Portuguese.³⁶ According to one study,²⁸ ANSD/CI individuals achieved an average S/N ratio of 58.2 dB in quiet conditions, and of 7.6 dB in noise with the application of HINT adapted into Portuguese. In another study,²⁹ the results showed that ANSD/CI children had an average S/N ratio of 60.7 dB in quiet conditions and of 7.1 dB in noise in their first assessment of speech perception. However, in their second assessment, children with ANSD had an average S/N ratio of 57.4 dB in quiet conditions and of 2.1 dB in noise.

Considering the importance of the evaluation of the speech perception in noise and the numerous reports of ANSD/CI individuals obtaining levels of hearing skills necessary for speech recognition in quiet conditions, we expected to find many more studies applying speech perception tests in noise in this population. However, it is also important to note that some studies have reported that individuals with ANSD are able to distinguish words or sentences in quiet conditions, but have difficulties in speech discrimination in noise.³³ The use of CI contributes to an improvement in speech perception, but does not necessarily guarantee speech understanding in noisy situations. Thus, further investigation regarding the performance in noise is needed.

It is worthwhile to mention that we found no studies that specifically reported age and rate of development of hearing skills in children with ANSD after CI surgery.

There were significant differences related to the children's age and to the period of CI use. Thus, it is important to note that the differences in age at evaluation and surgery, as well as the period of CI use in each study, should be considered, since the association between the development of hearing and language skills and these variables is well established. Therefore, the heterogeneity of these factors could result in a population with a wide range of hearing skills results.

Table 2 Comparison of results of hearing recognition and understanding, related to the time of CI use in children with ANSD and SNHL; both groups CI users.

Time of CI use	Hearing skills					
	Children with ANSD using CI			Children with SNHL using CI		
	Hearing recognition		Hearing understanding	Hearing recognition		Hearing understanding
	Words	Sentences		Words	Sentences	
6 months	–	5% Jeong et al. (2007)	–	–	20% Jeong et al. (2007)	–
1 year	Monosyllabic 100% Word recognition test (GASP) 100% Peterson et al. (2003)	–	–	Word recognition test (GASP) 100% Peterson et al. (2003)	–	–
1 year 6 months	Word recognition test (GASP) 66–75% Schramm et al. (2010)	HINT-C in quiet condition 76 dB Schramm et al. (2010)	–	Word recognition test (GASP) 66–75% Schramm et al. (2010)	HINT-C in quiet condition 78.9 dB Schramm et al. (2010)	–
2 years	Word recognition test (GASP) 75% Chisholm et al. (2010)	–	–	Monosyllabic 96–100% Word recognition test (GASP) 83% Peterson et al. (2003)	50–90% Peterson et al. (2003)	–
3 years	Word recognition test (GASP) 83% Peterson et al. (2003) Speech recognition in closed set 61% Speech recognition in open set 33% Carvalho et al. (2011)	100% Jeong et al. (2007) HINT-C in quiet condition 80 dB and in noise condition (20 S/S/R) 45 dB Peterson et al. (2003)	70–100% Peterson et al. (2003) HINT-C, HA users: 86–98 dB Pelosi et al. (2013) 67–98 dB HINT-C in quiet condition Pelosi et al. (2012)	Speech recognition in closed set 71% Speech recognition in open set 29% Carvalho et al. (2011)	90% Jeong et al. (2007)	–
4 years	Monosyllabic 95% Kim et al. (2011)	–	HINT-C 63–98 dB 4 years 3 months of CI use Pelosi et al. (2013)	Monosyllabic 73% Kim et al. (2011)	–	–
5 years	Monosyllabic 95% Kim et al. (2011) Monosyllabic – HA users 24.8–55.1% CI users 20.6–59.6% Rance et al. (2008)	–	–	Monosyllabic 70% Kim et al. (2011) Monosyllabic 53–83.1% Rance et al. (2008)	HINT-C in quiet condition 80 dB Peterson et al. (2003)	–

Table 2 (Continued)

Time of CI use	Hearing skills					
	Children with ANSD using CI			Children with SNHL using CI		
	Hearing recognition		Hearing understanding	Hearing recognition		Hearing understanding
	Words	Sentences		Words	Sentences	
6 years	Monosyllabic 95% Kim et al. (2011)	–	The Hearing in Noise Test (HINT) adapted to Portuguese idiom by Bevilacqua et al. (2008) Quiet condition 58.2 dB Noise condition (S/R) 7.6 dB Yamaguti (2013)	Monosyllabic 80% Kim et al. (2011)	–	The Hearing in Noise Test (HINT) adapted to Portuguese by Bevilacqua et al. (2008) Quiet condition 58.4 dB Noise condition (S/R) 7.7 dB Yamaguti (2013)
7 years	–	–	Results of 1st assessment: quiet condition 60.7 dB Noise condition (S/R) 7.1 dB Results of 2nd assessment: quiet condition 57.4 dB Noise condition (S/R) 2.1 dB Fernandes (2013)	–	–	Results of 1st assessment: Quiet condition 57.1 dB Noise condition (S/R) 7.9 dB Results of 2nd assessment: quiet condition 54.1 dB Noise condition (S/R) 2.8 dB Fernandes (2013)

–, no report.

ANSD, auditory neuropathy spectrum disorder; SNHL, sensorineural hearing loss; CI, cochlear implant.

Final considerations

The results of this study suggest that after CI use, individuals with ANSD improve in the detection of speech sounds, speech discrimination, and the recognition of words and sentences, but still have difficulty in speech perception in noisy conditions.

The selected studies have shown that there is no difference in the test scores of the hearing skills of ANSD/CI children and CI children with sensorineural hearing loss, with respect to speech detection, discrimination, and recognition of words and sentences.

Long-term studies of ANSD/CI children aiming to evaluate the hearing perception of noise in relation to the site of injury and its influence as well as the time elapsed until these children reach the maximum performance of hearing skills are needed, in order to guide the rehabilitation process in this population.

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Conflicts of interest

The authors declare no conflicts of interest.

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