

THE IMPLICATIONS OF THE COCHLEAR IMPLANT FOR DEVELOPMENT OF LANGUAGE SKILLS: A LITERATURE REVIEW

As implicações do implante coclear para desenvolvimento das habilidades de linguagem: uma revisão da literatura

Anderson Jonas das Neves⁽¹⁾, Ana Claudia Moreira Almeida Verdu⁽²⁾,
Adriane de Lima Mortari Moret⁽³⁾, Leandra Tabanez do Nascimento Silva⁽⁴⁾

ABSTRACT

The auditory rehabilitation by means of cochlear implant has constituted an field of interdisciplinary activity and research, whose interests have focused on the investigation of variables and processes related to the language skills of this population. This study aimed to present a systematic review of studies that investigated the relations between the use of cochlear implant and language development. For this, was conducted a search in scientific bases Web of Science®, Scielo® and LILACS®, of 2003-2013, the studies in scope of Audiology (and related areas), Education, Rehabilitation and Behavioral Sciences; applying the terms “cochlear implant”, “auditory recognition”, “recognition”, “speech”, “speech production” and “language”. After an initial processing of the results, were selected for analysis 86 articles that were classified according to the following criteria: year of publication, journal, research area, study type, skill and investigated topic. The results indicate growing progress in these studies and an emphasis on evaluating and/or identify possible factors that interfere language processes' cochlear implant users, and that these research conducted majority by the Audiology and related areas. The comparative and explanatory studies were the most frequent and have emphasized the auditory skills, specifically the factors that affect the auditory perception. While future perspectives, can be glimpsed largest scientific involvement of interdisciplinary areas of Audiology, expansion of research on expressive skills (such as oral production) and promotion of studies investigating interventions (evidence-based practices) in language to the public.

KEYWORDS: Cochlear Implants; Language Development; Review Literature as Topic

⁽¹⁾ Universidade Federal de São Carlos, UFSCar, São Carlos, SP, Brasil.

⁽²⁾ Universidade Estadual Paulista, UNESP, Bauru, SP, Brasil.

⁽³⁾ Departamento de Fonoaudiologia e Programa de Pós-Graduação em Fonoaudiologia, Faculdade de Odontologia de Bauru (FOB), Universidade de São Paulo, USP, Bauru, SP, Brasil.

⁽⁴⁾ Centro de Pesquisas Audiológicas do Hospital de Reabilitação de Anomalias Craniofaciais, HRAC, Bauru, SP, Brasil.

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■ INTRODUCTION

Hearing loss is among the most common disabling conditions in decades and affects about 5.3% of the world population¹. Of this quota, 8.9% are children under 10 years of age¹, with an incidence of congenital hearing loss from 1.5 to 5.95 every 1000 births^{1,2}. These international statistics approached proportion to the Brazilian census data of 2010, that is, approximately 5.10% of the population has some hearing loss and 10.3% of these are children or young people up to 19 years of age, with congenital and / or acquired frames in the first years of life^{2,3}.

Considering the impact on language development and implications for the individual's quality of life, this study highlights sensorineural type hearing loss, severe-profound, bilateral and pre-lingual^{4,5}. Hearing loss can be defined as sensorineural if damage is identified in the auditory nerve or hair cells in the cochlea (present in the inner ear). Regarding the auditory thresholds, it is considered severe to profound if the individual only hear sounds above 70 dB (between 71-90 dB, severe and, above 91 dB profound). Laterality, it is called bilateral when both ears are affected. The pre-lingual expression, in turn, indicates that hearing loss has occurred prior to the acquisition of language^{4,5}. This diagnosis constitutes an important component for making decisions of rehabilitation in order to direct the clinical management and the indication of electronic devices for deafness, such as the cochlear implant⁴⁻⁶.

The cochlear implant is a biomedical device surgically implanted in the cochlea that performs the function of the hair cells of the Organ of Corti by electrically stimulating the remaining auditory nerve fibers^{4,7}. This stimulation, in turn, produces an auditory sensation to the subject that allows the detection of sounds, especially speech sounds^{4,6,8}.

Generally, cochlear implants function from the same principle, namely the processing of auditory stimuli for electric stimuli^{6,8} and is configured as one of the important features that have been developed for auditory rehabilitation in the last decades⁹. Given the technological potential that it offers, this device has been recommended mainly for severe/profound hearing loss bilateral neurosensorial conditions (who not obtained gains from conventional hearing aids), but studies have also shown the benefits in other auditory pathologies (such as Auditory Neuropathy Spectrum Disorder) and multiple deficiencies cases^{5,6}.

One of the main, if not the main target of auditory rehabilitation of the cochlear implant is the development of language (ie, the ability to abstract and symbolize linguistic signs in a meaningful and contextualized way, allowing interaction and communication between people of the same linguistic community⁷) in oral modality, especially when it comes to children with pre-lingual auditory hearing loss⁷⁻¹⁰. Following this concern, researchers have obtained important findings about what variables and processes are related to the language development of these children¹⁰, conditions that could improve auditory skills⁵ and possible relations that these establish with the development of expressive skills, such as speech production^{6,11}.

Studies have shown that language development of cochlear implant users, especially in children with

pre-lingual hearing loss, may be related to specific factors⁷. The age of implantation, time of use of cochlear implant, previous auditory skills, auditory rehabilitation and the educational environment has been identified as components that interfere with the language processes of this public^{6,10-12}.

The point is that hearing plays an important role in the development of spoken language, in that it directs and facilitates the skills considered more complex, such as the production and the recombination of phonemes, which is a basis of speech¹³. Considering that are habilitation program with the cochlear implant establishes goals for auditory skills and spoken language^{4,13}, the aim of this study was to expose a literature review on this subject.

Specifically, this study aimed to identify and describe the current panorama of research produced on cochlear implants and language, from 2003 to 2013. The route was through the selection of studies published in journals indexed in national and international impact databases, within some areas of knowledge (the areas of Audiology, Speech and Language Pathology, Rehabilitation, Education and Behavioral Sciences) with the aim view of what types and under what conditions the investigations were performed, and therefore, which is the current knowledge about the use of cochlear implants and the relationship established with the development of language (especially speech).

■ METHODS

For the national and international literature review on the subject, article searches were performed in the Web of Science, SciELO (Scientific Electronic Library Online) and LILACS (Latin American and Caribbean Health Sciences) data bases during the period from June 1st to the 30th, 2013. Published studies were selected up to that date which met the following eligibility criteria: (1) contemplated research articles or review studies (article or review), (2) related areas of research (research area) of *Audiology, Speech and Language Pathology, Rehabilitation, Education and Behavioral Sciences*, respectively, in English. (3) those which were published between 2003 and 2013. The selection of publications in the delimited period had the intention of covering the largest number of recent studies on the subject, which could provide a current overview of the research field and signal some future research prospects.

The uni-terms or keywords applied in this review were: "*cochlear implant*", "*auditory recognition*", "*recognition*", "*speech*", "*speech production*" and "*language*", which were exchanged with syntaxes/expressions of three to four terms for electronic

search, ie: “cochlear implant [AND] auditory recognition [AND] speech [AND] language”, “cochlear implant [AND] auditory recognition [AND] speech production”, “cochlear implant [AND] recognition [AND] speech [AND] language” and “cochlear implant [AND] recognition [AND] speech production”. These multiple combinations of uni-terms aimed at offering the tracking of the greatest possible number of studies that explore the theme in question.

Analysis procedure of the results

Initially, the survey considered valid all derivative search studies of exchanged uni-terms that met the criteria, regardless of whether the records found were repeated. For each selected study, additional information was collected, such as title (title), authors (author), year (year published), periodical

(source), volume (volume), number (issue) and research area (research area), which were shown by refinement tools available in the databases. Already descriptive data such as type of study, approached skill, objectives, participants, procedure and results were extracted from the complete article that was available.

In the second step, the results were compiled and integrated in a single database. The studies reported in more than one expression of terms (i.e., repeated) were recorded on only one (the others being deleted), which allowed an actual survey of how many and which of these articulated the subject. The analysis procedure of the data was the categorization of articles by investigating the variables “year” (year published), “magazine” (source), “research area” (research area), “type of study”, “approached skill” and “specific phenomena”.

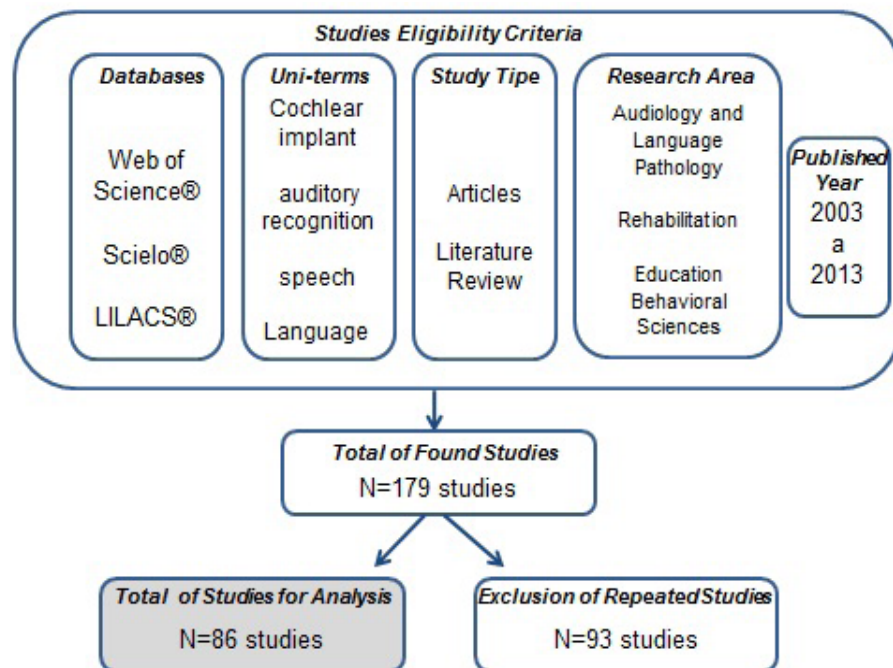


Figure 1 – Diagram of studies number found and selected after a strategy of search and analysis of inclusion and exclusion criteria

■ LITERATURE REVIEW

The initial survey of the studies, to be compiled into a single database, added 179 records of scientific works on the subject. After the exclusion of repeated studies, a reduction of 48.04% of the records was noted, computing 86 articles.

The scientific production on the relation between cochlear implants and language skills were mostly found in international journals indexed in the *Web of*

Science®, corresponding to 95.35% of the records. This finding may be explained, among several hypotheses, by the time and consolidation of this research front on the international scene, especially in countries like the United States and Germany⁵.

National studies comprised 4.65% of the records (four studies), three studies indexed in Scielo and one in the LILACS database. One hypothesis about the Brazilian scientific production detected on this topic may be due to it being spread on

different fronts/research problems - such as studies on electrophysiological¹⁴ and psychological¹⁵ aspects- published in journals indexed in other databases and with different descriptors than those employed in that review. There are few studies that specifically see the relations between the cochlear implant, language, auditory recognition and speech production. Another hypothesis to be entertained is the recency of researcher groups when compared to international centers, since they were created in the mid-1990s, due to the first cochlear implant surgeries in Brazil¹⁶.

The 86 articles considered valid underwent different analysis, guided by the research of variables of the year (year published), journal (source), research area (research area), study type, approached skill and specific phenomenon.

Analysis by Publication Year

Figure 2 shows the number of articles published by year during the period 2003 to 2013. The absolute-frequency curve is shown in gray and the cumulative frequency in black.

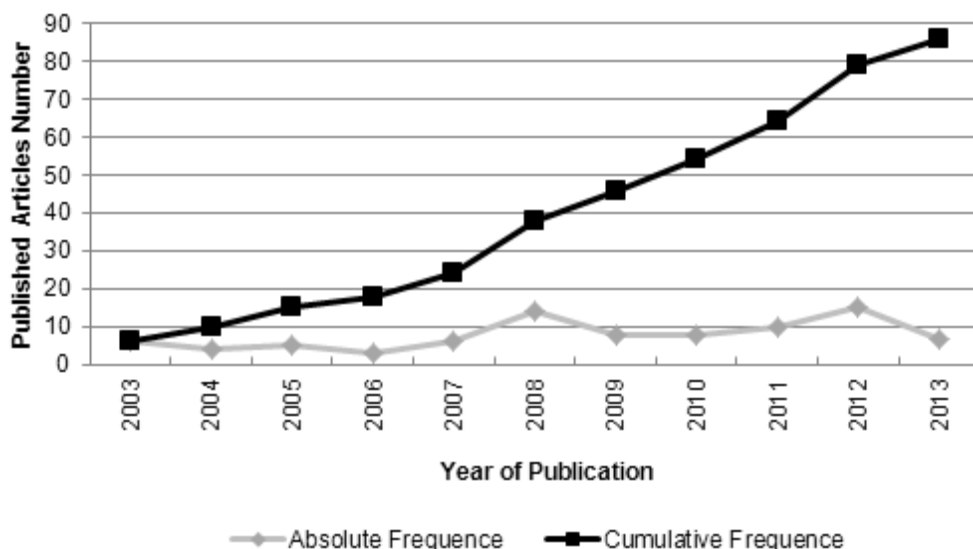


Figure 2 – Number of scientific publications relate to subject, by publication year, from 2003 to 2013, registered as absolute-frequency and cumulative-frequency curves

A steady increase of articles on the relation between the cochlear implant and language was observed, being evidenced by the cumulative frequency curve in constant positive acceleration. In the first five-year period observed (2003-2008), a gradual increase in publications was noted, with a significant leap in 2008 (14 articles), totaling 38 studies. Already in the period between 2009 and the first half of 2013, there was a higher science production rate of 26.31%, compared to the previous five years, and these studies represented 55.81% of the total found in this literature review.

These results show a continuous increase in articles that portrayed the benefits of cochlear implants on the language processes. The growth of this scientific production can be explained/speculated by some political, technological, scientific and educational factors.

In the political sphere, a gradual expansion and consolidation in policies in the area of hearing health was observed in the last decades, both in developed (like the United States, Germany and England) and emerging (Brazil, China and India, for example) countries⁵. One effect of these policies was the intensification of early diagnosis of severe-profound hearing loss (in neonatal auditory screening, for example), quick insertion in hearing assistance programs and increased indication of cochlear implants, mobilizing the scientific community to endorse with studies on how this device has promoted language development⁵. It is noteworthy that there is a considerable variation in funds invested by each country for the purchase of cochlear implants, since this device still requires high financial investment⁵.

Although Brazil has established important steps in the direction of these policies (such as

the implementation of the National Hearing Health Policy in 2004) and is contextualized in this juncture of internationalization, there is still a reality that little corresponds to the international scenario¹⁷. That condition can be explained, at least in part, by the irregular distribution of hearing health services in territorial extension and insufficient financial resources, and other socio-political complications in the consolidation of reference centers for this part of the public¹⁷.

Given the international context of hearing health policies, greater investment in such research can be seen, which have been conducted by groups linked to cochlear implant services, with public and/or private support. In general, these research groups have sought to endorse the effectiveness of this technology (and the consequent subsidy by the government and/or health plans) and provide evidence for changes in current policies, as the implementation of bilateral cochlear implant by groups in the United States, Germany, England^{6,9} and more recently in Brazil¹⁸.

The advancement and technological enhancement in cochlear implant devices can be another important factor in the growth of researches^{6,19,20}. From 2003 to 2013, companies have produced models of cochlear implants with important differences in the components (such as waterproof devices, for example), the programming and mapping software and the coding strategies (such as CIS, SPEAK and ACE); these changes, in turn, may imply distinct effects on perception of speech sounds and, therefore, the development of auditory skills and oral production^{5,20}. An example

of this was the investment in the production of processors with increasingly sophisticated technologies that enable a high level of refinement of the captured sound stimuli²⁰ which demanded research on the possible effects of these on the auditory detection/discrimination and cost-effectiveness among the models²⁰.

Scientific and educational determinants may have further supported the current panorama. In the scientific field, we can infer that the foundation and consolidation of research groups in the cochlear implant services (of multi-professional character and linked to universities and centers of reference) have provided a favorable condition for research, monitoring and intervention in cochlear implant users^{16,20-22}.

Still, the growing demand for students with cochlear implants in the last decades may have been another factor. The inclusion of these students in the common education system and the indications of academic and language difficulties (in some cases)^{5,10} may have encouraged researchers to investigate the relation between the use of cochlear implants and the development of auditory and language skills, as well as the ramifications for reading and writing acquisition processes^{11,23,24}.

Analysis by Journal

The impact journals that are indexed in the databases investigated in this work (Web of Science, SciELO and LILACS) represent recognized dissemination channels of scientific importance in the field of various sciences. Figure 3 illustrates the distribution of studies based on journals found in this review.

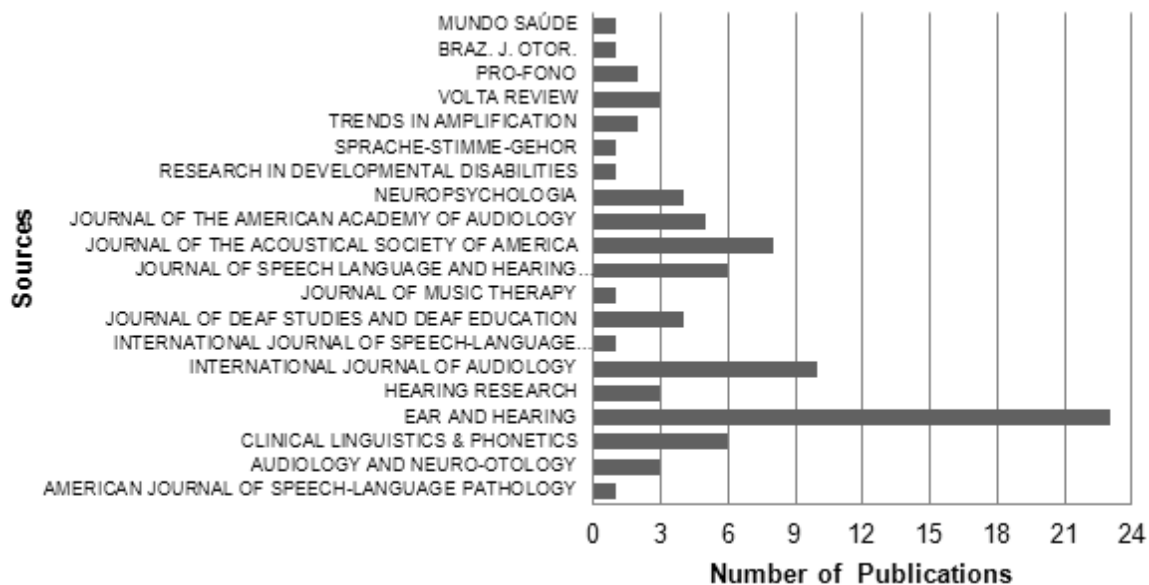


Figure 3 – Number of scientific articles by sources, from 2003 to 2013

The dissemination of studies on cochlear implants and language was concentrated in two international journals, namely, *the Ear and Hearing and International Journal of Audiology*, which jointly provides 38.37% of the total scientific production (33 articles) in this study. Traditionally, these two journals include Audiology, hearing, hearing impairment, auditory rehabilitation and applied technologies in its scope topics, which may explain, in part, the prevalence (in quantitative terms) of the studies found about cochlear implants and language.

The periodicals *Clinical Linguistics & Phonetics* (6 articles), *Journal of Acoustical Society of America* (8 articles) and *Journal of Speech Language and Hearing Research* (6 articles) provide, in addition, 23.25% of the published studies of this review. The remaining 33 articles (38.38%) are distributed in 15 other journals.

One data that drew attention refers to the fact that although there is a concentration of studies in journals in Audiology and related areas (such as the *Ear and Hearing*, *International Journal of Audiology* and *the Journal of Speech Language and Hearing Research*), that can be noted as journal under the scope of various areas of knowledge, such as Engineering and Physics (*Journal of the Acoustical Society of America*), Linguistics (*Clinical Linguistics & Phonetics*), Education (*Journal of Deaf Studies and Deaf Education*) and Psychology (*Neuropsychology*). This result may indicate that the studies related to cochlear implants have set up an interdisciplinary research field, in which each science can contribute to the research, technological upgrading, planning and intervention with this population.

Analysis by search area

Studies which dealt with the cochlear implant and the relations established with the language mainly integrated (85% of the total) a large area of research to Audiology and related sciences (Speech and Language Pathology). Audiology as a research field has studied “hearing, vestibular and its disorders and related processes, as well as the means to prevent, identify, evaluate, diagnose and intervene in hearing and vestibular disorders in children, adults and seniors”¹⁷. Given this study object, the concentration of studies in this area is justified, in part.

However, given the complexity of the phenomena involving the cochlear implant and language, knowledge coming from other scientific fields have established interfaces with Audiology, such as Engineering, Physics (especially the acoustics area), Genetics, Otorhinolaryngology, the Rehabilitation Sciences, Education and Psychology. From this perspective, studies related to cochlear implants have configured an interdisciplinary research field, as can be seen by the large list of journals from other areas.

It was noted that other areas selected in this review (Rehabilitation, Education and Behavioral Sciences) presented a low production in these studies (15% of the articles found), distributed in three of the Behavioral Sciences, eight in the field of Education and two in Rehabilitation. This panorama, duly illustrated in Figure 4, indicates a lack of studies of the interface areas with Audiology and the need for greater investments and the involvement of these to investigate language processes in cochlear implant users.

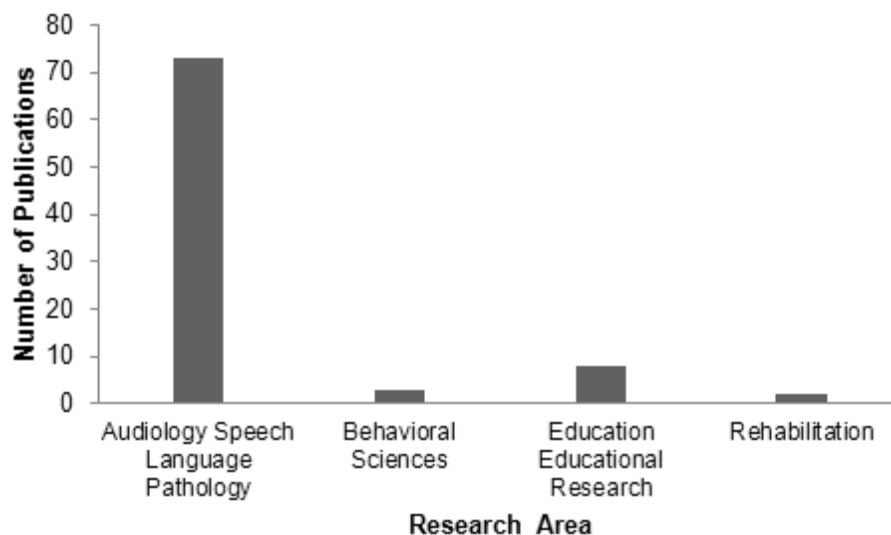


Figure 4 – Number of scientific publications relate to subject, by research area, from 2003 to 2013

Analysis by Study Type

The studies can also be classified with based on the methodological designs and goals, which are important components of research, establishing conditions under which scientific results are produced²⁵. That categorization of study type is not

consensual, however possible identified object/subject scientifically discussed, which possible gaps and methodological refinements are still necessary²⁵.

Figure 5 represents the number of articles selected according to the type of study.

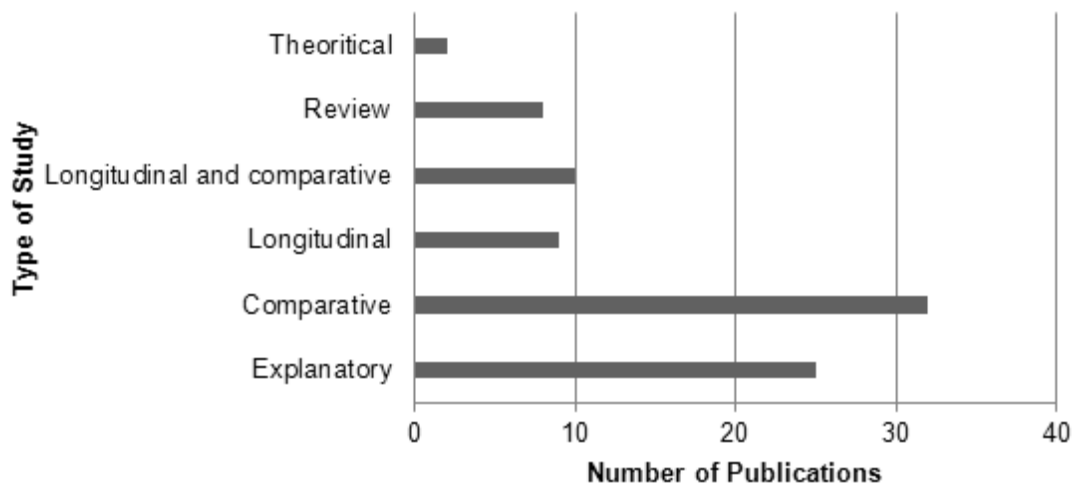


Figure 5 – Number of scientific publications relate to subject, from 2003 to 2013, defined by study type

By definition, studies of comparative type aim to analyze, in single or multiple aspects, the similarities and differences between the conditions, problems and populations²⁵. In this review, there was a prevalence of this type of research (37.21%, the equivalent of 32 articles), which have compared language skills (receptive and expressive) between different groups, by controlling systemic of variables (such as hearing, the time of use of cochlear implant, age, gender, speech processor and education).

With distinctive designs, such studies have made it possible to establish relation between language skills and some specific features, for example the development of auditory skills and the time of use of cochlear implant. The comparisons observed were between groups of: children with cochlear implants and normal-hearing peers (13 articles); adults with cochlear implants and normal-hearing peers (6 articles); adults with post-lingual and pre-lingual cochlear implants (2 articles); children with cochlear implants and children with hearing aids (1 article); children with cochlear implants and children with hearing loss and without cochlear implants (1 article); children with cochlear implants with greater time of use and with less time of use (3 articles); children with cochlear implants, hearing aids and children with normal hearing peers (3 articles); children with cochlear implants, deaf children without cochlear implants and normal-hearing peers (1 article); children with cochlear implants, normal-hearing

peers and normal hearing adults (1 article); and adults with cochlear implants in different sound environment conditions (1 article).

The explanatory studies are defined depending on the objective of the identifying factors that influence the phenomenon (without necessarily controlling the variables)²⁵ and represent in this review, the second most frequent type of study (29.07%, 25 articles). In the scope of this theme, these surveys have evaluated and measured skills in the area of language, from the measured variables (such as time of use of cochlear implant, age, gender, speech processor, education, etc.)^{26,27} and have established possible correlations, such as the perception of speech in Mandarin in cochlear implant users with a particular speech processor²⁸.

It was observed that the comparison of language skills between groups (usually cochlear implant users and normal-hearing peers) over a certain period (six months, on average) was a target of 10 studies of this review (11.63%) which can be classified as comparative longitudinal studies²⁵. Other types of studies (theoretical, only longitudinal and literature review²⁵) amounted to a total of 22.09% of the analyzed studies (19 articles).

It is noteworthy that we found no studies that describe the effects of training/education programs of auditory and expressive abilities, with or without an experimental design. This finding may show a lack of these studies in delimited areas (namely

Audiology, Speech and Language Pathology, Rehabilitation, Education and Behavioral Sciences) and, therefore, provide a need for applied research that address issues regarding auditory rehabilitation and strategies for teaching language skills.

Analysis by approached skill

The skills identified in this review were classified into auditory, expressive and, auditory and expressive. Auditory skills are defined by relation established with auditory stimuli and described by

Audiology as detection, discrimination, recognition and comprehension^{4,13}. The expressive skills, in turn, are characterized by communication actions in which individuals express themselves through speech, writing and reading^{7,29}.

Given the scope of this analysis by skill, visual skills were also incorporated into the study, such as visual attention. These skills are considered important components for language, since they are prerequisites for the acquisition of linguistic skills²⁹. Table 1 shows the distribution of studies according to the categories of skills.

Table 1 – Distribution of studies by categories of dealt skills

Dealt Skill	Percentage of studies	Studies
Visual Skill	1,16% (n=1)	Horn, Davis, Pisoni, Miyamoto (2005)
Auditory Skill	53,49% (n=46)	Bergeson, Pisoni, Davis (2003); Boothroyd (2010); Bouton, Serniclaes, Bertoncini, Cole (2012); Chen, Loizou (2011); Chung, Nelson, Teske (2012); Coez, Belin, Bizaguet, Ferrary, Zilbovicius, Samson (2010); Eisenberg, Johnson, Martinez, Cokely, Tobey, Quittner, Fink, Wang, Niparko (2006); Erb, Henry, Eisner, Obleser (2012); Francis, Yeagle, Bowditch, Niparko (2005); Fu, Hsu, Horng (2004); Giezen, Escudero, Baker (2010); Champoux, Lepore, Gagne, Theoret(2009); Angelo, Bevilacqua, Moret(2010); Souza, Brito, Bento, Gomez, Tsuji, Hausen-Pinna(2011); Sant'Anna, Eichner, Guedes (2008); Gifford, Olund, DeJong (2011); Grieco-Calub, Saffran, Litovsky (2009); Han, Liu, Zhou, Chen, Kong, Ying, Liu, Zheng, Xu (2009); Ji, Galvin, Xu, Fu (2013); Johnston, Durieux-Smith, Angus, O'Connor, Fitzpatrick (2009); Johnstone, Yeager, Noss (2013); Kovacic, Balaban (2010); Krenmayr, Qi, Liu, Liu, Chen, Han, Schatzer, Zierhofer (2011); Lee, van Hasselt (2005); Litovsky, Goupell, Godar, Grieco-Calub, Jones, Garadat, Agrawal, Kan, Todd, Hess, Misurelli (2012); Liu, Liu, Wang, Liu, Kong, Zhang, Li, Yang, Han, Zhang (2013); Meister (2011); Mendel (2008); Milczynski, Chang, Wouters, van Wieringen (2012); Mildner, Sindija, Zrinski (2006); Morton, Torrione, Throckmorton, Collins (2008); Newman, Chatterjee (2013); Peng, Chatterjee, Lu, (2012); Pisoni, Cleary (2003); Santarelli, De Filippi, Genovese, Arslan (2008); Cullington, Zeng (2011); Shafiro, Sheft, Gygi, Ho (2012); Stohl, Throckmorton, Collins (2009); Tse, So (2012); Vongphoe, Zeng (2005); Wei, Cao, Jin, Chen, Zeng (2007); Wong, Vandali, Ciocca, Luk, Ip, Murray, Yu, Chung (2008); Xin, Fu (2004); Smith, Burnham (2012); Zhou, Zhang, Lee, Xu (2008); Kovacic, Balaban (2010); Hsiao (2008)
Expressive Skill	15,12% (n=13)	Dillon, Cleary, Pisoni, Carter (2004); Todd, Edwards, Litovsky(2011); Jones, Gao, Svirsky (2003); Liker, Mildner, Sindija (2007); Titterington, Henry, Kramer, Toner, Stevenson (2006); Ronnberg, Rudner, Foo, Lunner(2008); Tye-Murray (2003); Zhou, Xu(2008); Nittrouer, Caldwell, Lowenstein, Tarr, Holloman(2012); Mildner, Liker(2008); Tobey, Thal, Niparko, Eisenberg, Quittner, Wang (2013); Strelnikov, Rouger, Lagleyre, Fraysse, Deguine, Barone (2009); Most, Levin, Sarsour(2008)
Auditory and Expressive Skills	30,23% (n=26)	Tobey, Britt, Geers, Loizou, Loy, Roland, Warner-Czys, Wright (2012); Eisenberg, Johnson, Martinez, Visser-Dumont, Ganguly, Still (2012); Vermeulen, van Bom, Schreuder, Knoors, Snik (2007); Eisenberg, Martinez, Boothroyd (2003); Burkholder-Juhasz, Levi, Dillon, Pisoni (2007); Sininger, Grimes, Christensen(2010); Wie, Falkenherg, Tvete, Tomblin(2007); Fairgray, Purdy, Smart(2010); Leigh, Dettman, Dowell, Sarant(2011); Peng, Tomblin, Cheung, Lin, Wang (2004); Peng, Tomblin, Turner (2008); Desjardin, Ambrose, Martinez, Eisenberg(2009); Coelho, Bevilacqua, Oliveira, Behlau(2009); Ambrose, Fey, Eisenberg(2012); Harris, Kronenberger, Gao, Hoen, Miyamoto, Pisoni (2013); Holt, Svirsky(2008); Geers, Brenner (2003); Dettman, Pinder, Briggs, Dowell, Leigh (2007); Nicholas, Geers(2008); Wu, Chen, Chan, Lee, Hsu, Lin, Liu (2011); van Besouw, Grasmeder, Hamilton, Baumann(2011); Holt, Kirk (2005); Dillon, de Jong, Pisoni(2012); Coopens, Tellings, van der Veld, Schreuder, Verhoeven (2012); Schwartz, Steinman, Ying, Mystal, Houston (2013); Johnson, Goswami(2010)

Noted were the most frequent researches that approached auditory skills, with a total of 46 articles. This finding may indicate, in part, an engagement of the scientific community to study the processes of development of auditory skills via cochlear implant^{5,20}. Yet, this emphasis can be endorsed by the rapid improvement of technology of this device (especially the speech processor)²⁰, which promotes researches (recommended or not by companies) on the effects of these technological refinements in certain auditory skills.

Thirteen researches that only highlighted the expressive skills were found. Although the number of studies is small, the interest to investigate these skills (especially in pre-lingual cochlear implant users), could constitute a research front, given the evidence that even after the acquisition of auditory skills, the expressive skills do not follow the same rhythm and incur commitments (such as in speech intelligibility)²².

An interesting finding refer the range of research that overlap the auditory and expressive skills, of which corresponded to 30.23% (26 articles). Guided by the premise that the functions of hearing and language are interdependent and correlated^{2,29,30}, these studies have determined to what extent the skills involved in listening have interfered in

the expressive abilities, particularly in the speech production of this public. Indeed, these findings may have significant ramifications for the auditory rehabilitation process, to the extent that they seek to identify what conditions cause the aspects of listening and speaking to interrelate^{5,13,31}.

Only one survey focused on the visual skills³². When comparing groups of children with normal-hearing and cochlear implant users in visual attention tasks, the study found that cochlear implant users showed improved visual attention after two years of using the device, with gains in reading and writing processes.

Analysis by phenomena

Studies of this review were submitted to a categorization by phenomena, carried out by reading the articles in full. Seven phenomena were found in the scope of research on cochlear implants and language: variables involved in speech perception (24 articles), relations between receptive and expressive repertoires (23 articles), research programs (3 articles), oral production (14 articles), other phenomena (5 articles), bilateral cochlear implant (3 articles) and auditory skills in tonal languages (14 studies). Figure 6 shows the distribution of studies by said categorization.

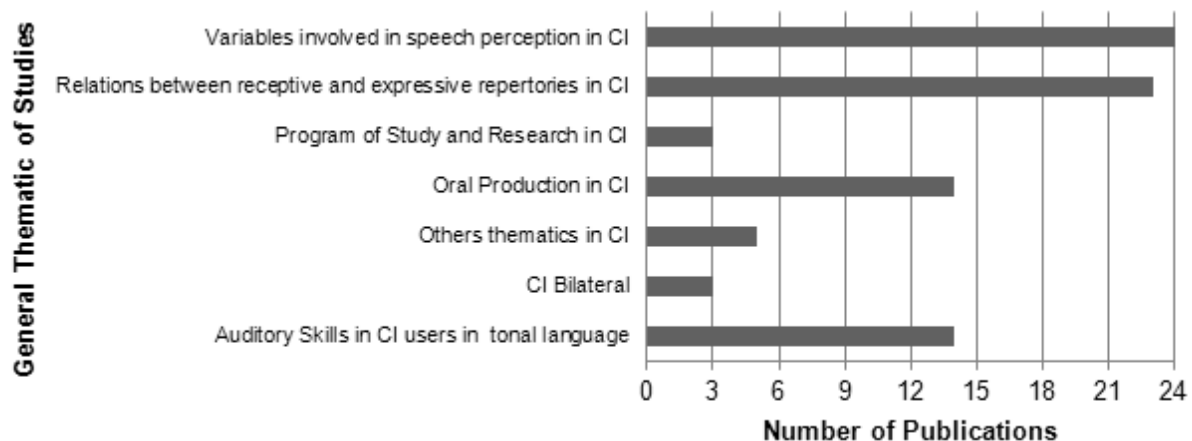


Figure 6 – Number of scientific publications by investigated phenomenas in studies, from 2003 to 2013

The phenomenon “variables involved in speech perception” included studies that evaluated and measured the effects of the independent variables - technological (such as different speech processors), audiological (use of cochlear implants, type of auditory training), linguistic (such as intonation, tone and speech rhythm) and contextual (silence-noise environments with competition from sound sources)

character – in the discrimination and perception of speech sounds for pre and/or post-lingual cochlear implant users.^{26,33}Such theme corresponded to 27.9% of the studies and refined the data found regarding the prevalence of research in auditory skills (see Table 1), indicating that speech perception has focused the production of research in the area. Considering that they perceive and behave

differentially regarding speech stimuli, it constitutes one of the basic listening skills, investigations that verify all of the variables that affect the perception of this public becomes crucial, in order to offer technological and rehabilitation conditions so that they may acquire it.

The phenomenon “Relations between auditory and expressive skills” involved research that has been engaged in identifying, evidencing and forecasting the effects that listening skills (such as auditory discrimination, recognition and comprehension) have on the development of expressive language (especially oral production), especially for children with pre-lingual cochlear implants. Accounting for 26.74% of the total research, such as that of Dettman et al,³⁴ - included in that category - can synthesize some of the questions that have directed these studies: What are the relations established between the listener and speaker repertoires in pre-lingual cochlear implants users? What are the auditory skills that interfere in acquiring expressive skills? And what auditory skills are needed for the development of speech and oral language?

The phenomenon “Research program” consisted of studies describing scientific programs developed by some referral centers of cochlear implants. With 3.49% of the total of this review, these studies proposed to review and specifically expose the research program such as the *Dallas’sCenter*²¹ and *HouseResearchInstitute*⁸.

Another phenomenon which included 3.49% was the “Bilateral cochlear implantation”. It was composed of research about binaural hearing by cochlear implants, with an interest in investigating whether this condition interferes with the acquisition of auditory skills, the time of auditory rehabilitation, academic performance and quality of life^{9,35}.

It should be noted that the phenomena “Relations between auditory and expressive skills”, “Research program” and “Bilateral cochlear implantation” encompassed recent studies, starting from 2011. This scenario allows speculation for the tendency of research for years to come. Other phenomenon of interest that may also have an increase in scientific production refers to “Hearing abilities in tonal languages” and “Oral production”.

The 14 studies on “Hearing abilities in tonal languages” have investigated the variables that affect the auditory skills in cochlear implants users whose language is tonal, such as Mandarin and Cantonese^{36,37}. Such surveys are justified by the fact that in tonal languages, the tonal range of speech sets an important dimension to be perceived by the listener (unlike what happens in phonetic languages like English, Portuguese and Spanish) and can transmit different lexical meanings of words³⁷.

Thus, the cochlear implant models using certain processing strategies (CIS or SPEAK) and capture different tonal ranges may be insufficient to favor auditory accuracy in tonal perception, creating difficulties when cochlear implant users communicate with members of the verbal community^{5,30}.

The phenomenon “Oral production” consisted of 16.28% of the studies found and included the research role that evaluated and /or measured the dimensions of speech (such as intelligibility, rhythm and prosody), as well as the processes related to the acquisition of that skill by cochlear implants users. Studies such as Liker, Mildner and Sindija³⁸ were part of this category.

The rest of the research was composed of the category “Other phenomena.” Part of this group were studies that included evaluations and measurements of attention, memory and visual tracking of this public, establishing the necessary correlations with the language, such as the Pisoni and Cleary³⁹ and Horn, Davis, Pisoni and Miyamoto⁴⁰.

■ FINAL CONSIDERATIONS

The pioneering studies with cochlear implants were conducted by Djournò and Eyriès from year of 1957, but gained the due space in the mid-90’s, when the FDA (Food and Drug Administration) released it for medical use^{6,16}. Although the emergence of this scientific technology can be seen in recent years, a growing panorama of studies about the effects of this device for the areas of language, cognition, quality of life and public policies were observed⁵.

Regarding the implications of cochlear implants for the development of language, which was of interest in this review, an increase in the number of articles from 2003 to 2013 was noted, with optimistic projections for the coming years. Thus, such a scenario may suggest that the interface between cochlear implants and language have consolidated a research front, being a promising area for the insertion of researchers. Public policies for hearing health, technological advances, the joint research groups and the growing educational demands are important influences that allowed this current situation and will facilitate scientific development of this issue in the coming decades.

As can be seen, the scientific dissemination of this theme was mainly made by international journals and national studies represented less than 5% of that production. This result may indicate, among other things, that a gradual consolidation of this theme occurs in Brazilian research (in recent processes)¹⁶ and tend to occur in several countries^{8,21}.

Another important finding was that the Audiology and related areas (Speech and Language

Pathology) concentrated most studies, and the other sciences (Rehabilitation, Education and Behavioral Sciences), together held only 15% of this total. The limited production of these areas that interface with Audiology can serve as a clue to broaden their participation in research on cochlear implants and language in order to consolidate an interdisciplinary space.

These studies have been framed largely as comparative and explanatory and researches, are not found that refer to intervention and / or teaching of language skills. In this sense, studies that prioritize aspects of intervention, rehabilitation and teaching - with experimental designs (or not) intra-subject, inter-subject and groups - can favor useful knowledge about this public learning process and should require contributions from other areas of knowledge, such as Education, Psychology and Behavioral Sciences.

Auditory skills, especially the perception of speech in with tonal language cochlear implants users covers much of the research of this review.

This study list still requires continuity, given the specificities of speech perception tones for this public.

At the same time, the growth of the studies that integrate auditory and expressive skills can make up a front of interesting research. In this scope, some interface investigations have been monitoring the effects of teaching listening skills on the accuracy of oral production in naming tasks of object figures and actions³¹, requiring a sentence with [subject] - [verb] - [object].

Based on the findings of this literature review, it was possible to identify part of the scientific panorama on the subject of cochlear implants and language and envision future prospects. Some of these projections refer primarily to the phenomena of interest, such as bilateral cochlear implants^{9,10,19}, scientific and technological innovation for cochlear implants (like breakthroughs in speech processors and the possibilities of totally implantable cochlear implants)^{5,10,19} and strategies in auditory rehabilitation evidence-based^{10,19}.

RESUMO

A reabilitação auditiva por meio do implante coclear tem constituído um campo de atuação e de pesquisa interdisciplinar, cujos interesses têm incidido na investigação das variáveis e processos relacionados às habilidades de linguagem dessa população. O presente estudo teve como objetivo apresentar uma revisão sistemática das pesquisas que investigaram as relações entre o uso do implante coclear e o desenvolvimento da linguagem. Para isso, foi realizada uma busca nas bases científicas Web of Science®, Scielo® e LILACS®, de 2003 a 2013, de estudos sob escopo da Audiologia (e de áreas correlatas), Educação, Reabilitação e Ciências do Comportamento; aplicando os unitermos “*cochlear implant*”, “*auditory recognition*”, “*recognition*”, “*speech*”, “*speech production*” e “*language*”. Após um tratamento inicial dos resultados, foram selecionados para análise 86 artigos que foram classificados de acordo com os seguintes critérios: ano de publicação, periódico, área de pesquisa, tipo de estudo, habilidade investigada e a temática. Os resultados indicaram crescente avanço nesses estudos e uma ênfase em avaliar e/ou identificar possíveis fatores que interferem nos processos de linguagem de implantados cocleares, sendo essas pesquisas conduzidas majoritariamente pela Audiologia e áreas correlatas. Os estudos comparativos e explicativos foram os mais frequentes e têm destacado as habilidades auditivas, especificamente os fatores que afetam a percepção auditiva. Enquanto perspectivas futuras, poderão ser vislumbrados maior envolvimento científico de áreas interdisciplinares à Audiologia, ampliação de pesquisas sobre habilidades expressivas (como a produção oral) e fomento à estudos que investiguem intervenções (práticas baseadas em evidências) em linguagem para esse público.

DESCRITORES: Implantes Cocleares; Desenvolvimento da Linguagem; Literatura de Revisão como Assunto

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Mailing address:
Anderson Jonas das Neves
R. Cristiano Pagani, 8-51, 42F, Jardim Contorno
Bauru – SP – Brasil
CEP: 17047-144
E-mail: filosofoajn@gmail.com