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Systematic Review

Revisão Sistemática

Relationship between auditory perception and vocal production in cochlear implantees: a systematic review

Relação entre percepção auditiva e produção vocal em implantados cocleares: uma revisão sistemática

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ABSTRACT

Purpose: To conduct a systematic review of the scientific literature studying the relationship between vocal production and auditory perception in cochlear implant users. **Research strategies:** This is an integrative systematic review. The plattforms/databases Bireme, SciELO, Cochrane, Scopus and Web of Science were consulted and the descriptors used were voice, cochlear implant and auditory perception. **Selection criteria:** Original papers published in English, French, Spanish or Portuguese involving the study of vocal production and auditory perception in cochlear implant users were selected and there was no restriction about year of publication of the articles. **Data analysis:** The studies selected were analyzed according to the author, location, year and publication of the article, as well as for their sample size, type of vocal production and auditory perception assessment and for its major findings and recommendation grade/level of scientific evidence. **Results:** The results suggest the existence of positive relationship between vocal production and auditory perception in cochlear implant users, and indicate that the deployment time has a positive influence in this relationship. **Conclusion:** None of the selected studies were rated at level 1 of scientific evidence or grade A of recommendation, which is related to the methodological approach that can go with this subject matter. There is great lack of publications relating auditory perception and speech production in cochlear implant users. This gap is even greater when it comes to the adult population.

Keywords

Auditory Perception
Phonation
Cochlear Implantation
Voice
Audiology

RESUMO

Objetivo: Realizar uma revisão sistemática das publicações científicas que estudam a relação entre produção vocal e percepção auditiva em usuários de implante coclear. **Estratégia de pesquisa:** Trata-se de uma revisão sistemática da literatura. Foram consultadas as plataformas/bases de dados Bireme, Pubmed, SciELO, Cochrane, Scopus e Web Of Science e utilizados os descritores voz, implante coclear e percepção auditiva. **Critérios de seleção:** Artigos originais publicados nos idiomas inglês, francês, espanhol ou português, envolvendo o estudo da produção vocal e da percepção auditiva em usuários de implante coclear, foram selecionados e não houve restrição quanto ao ano de publicação dos artigos. **Análise dos dados:** Os estudos selecionados foram analisados segundo autor, local, ano e periódico de publicação, bem como por número amostral, tipo de avaliação da produção vocal e da percepção auditiva, por seus principais achados e grau de recomendação/nível de evidência científica. **Resultados:** Os resultados encontrados sugerem a existência de relação positiva entre produção vocal e percepção auditiva em usuários de implante coclear, bem como indicam que o tempo de implantação apresenta influência positiva nesta relação. **Conclusão:** Nenhum estudo selecionado obteve nível 1 de evidência científica ou grau de recomendação A, o que se relaciona com o caminho metodológico que se pode percorrer com este objeto de estudo. Há uma grande carência de publicações relacionando percepção auditiva e produção vocal de usuários de implante coclear. Essa lacuna é ainda maior quando se trata da população adulta.

Descritores

Percepção Auditiva
Fonação
Implante Coclear
Voz
Audiologia

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INTRODUCTION

Hearing loss can interfere with many aspects of emotional, psychological, social and intellectual life[1]. Its impact on the individual's communication is connected to the auditory feedback and its importance in monitoring and adjusting articulation and speech production[2].

As an alternative for restoring auditory feedback, there is the cochlear implant (CI), which is an electronic device that allows the auditory rehabilitation of individuals with severe/deep neural hearing loss and partially performs the functions of sensory cochlear cells directly stimulating the auditory nerve[3].

Studies indicate a post-implant improvement in sound localization ability (in the case of bilateral cochlear implant)[4], in speech recognition in quiet and in noise[5] and in the development pace of oral language[6] as well as significant benefits in vocal and prosodic terms in the child population[7].

The literature indicates that the CI is an intervention with beneficial effects for hearing detection and speech perception also in the adult population[8], showing improvements in hearing thresholds only three months after the cochlear implant[9], which demonstrates that the CI can provide many adults with an opportunity to improve their speech and communication skills[10].

There is a study[11] pointing improvements to vocal stability, as well as suggesting that individuals tend to have better conditions to expose a richer tone in terms of frequency and intensity during speech.

The same authors[11] also observed that current literature focuses mostly on language production and auditory perception. Those, however, who associate vocal production with auditory perception, are rare, especially in terms of national scientific production.

Considering the above-mentioned, the purpose of this study was to conduct a systematic review of the scientific literature studying the relationship between vocal production and auditory perception in cochlear implant users.

SEARCH STRATEGY

This study is characterized as a systematic literature review, conducted through electronic searches on the platforms/databases Bireme, SciELO, Cochrane, Scopus and Web of Science.

Studies published in English, French, Spanish and Portuguese were selected for analysis, although there were no restrictions on language or publication year of the articles. Studies published up to July 2014 were analyzed.

The Descriptors in Health Sciences (DeCS) selected were "voz, implante coclear and percepção auditiva." The corresponding English terms, from Medical Subject Headings (MeSH), "voice, cochlear implantation and auditory perception", were also applied, as well as their counterparts in Spanish, "voz, implantación coclear and percepción auditiva," plus the free term "cochlear implant".

The search strategy was constructed and conducted based on the following question: "What is the relationship between auditory perception and vocal production of cochlear implant users?"

The boolean operator adopted was the "AND" and search strategies, in pair of descriptors, were: voz AND implante coclear / implantation coclear; voice AND cochlear implantation / cochlear implant.

The search strategies used in groups of three descriptors were: voz AND percepção auditiva / percepción auditiva AND implante coclear / implantación coclear and voice AND cochlear implant AND auditory perception. Each strategy was applied to each of the selected platforms/databases.

INCLUSION CRITERIA

The inclusion criteria were: to be an original article; to study cochlear implantees; to involve the study of vocal production; to involve the study of auditory perception; to be published in Portuguese, English, French or Spanish. Articles whose analyzed material used tonal languages were excluded, given the specific of CI programming for speakers of tonal languages, once the latter make use of melodic curve to semantically change the message, differing much from the reality of speakers of non-tonal language, such as Portuguese.

The article selection was conducted by two reviewers, and a third one would be consulted in the event of doubt as to the inclusion of a particular study. According to the application of the search strategy, the selected articles were screened in three consecutive steps:

- Reading of titles in different electronic databases;
- Reading of the studies' summaries selected in the first step;
- Full reading of texts to select those included in this review.

All articles selected met the inclusion criteria established at the beginning of the methodological protocol of this study. The main information of each study was collected and entered into an MS Office Excel 2010 database. Below, an illustrative flow chart (Figure 1) to better understand the selection process of the final articles.

DATA ANALYSIS

For presentation of results, the following variables were considered into the selected articles: author, place of publication, year and publication journal; sample size; type of vocal production evaluation and type of auditory perception evaluation; the main findings and recommendation grade/level of scientific evidence, as shown in Table 1.

Regarding the level of scientific evidence, the Oxford Centre rating for Evidence-Based Medicine[17], last updated in 2011, was used. The grade of scientific recommendation was established in accordance with the criteria set out in the same source, last updated in 2009.

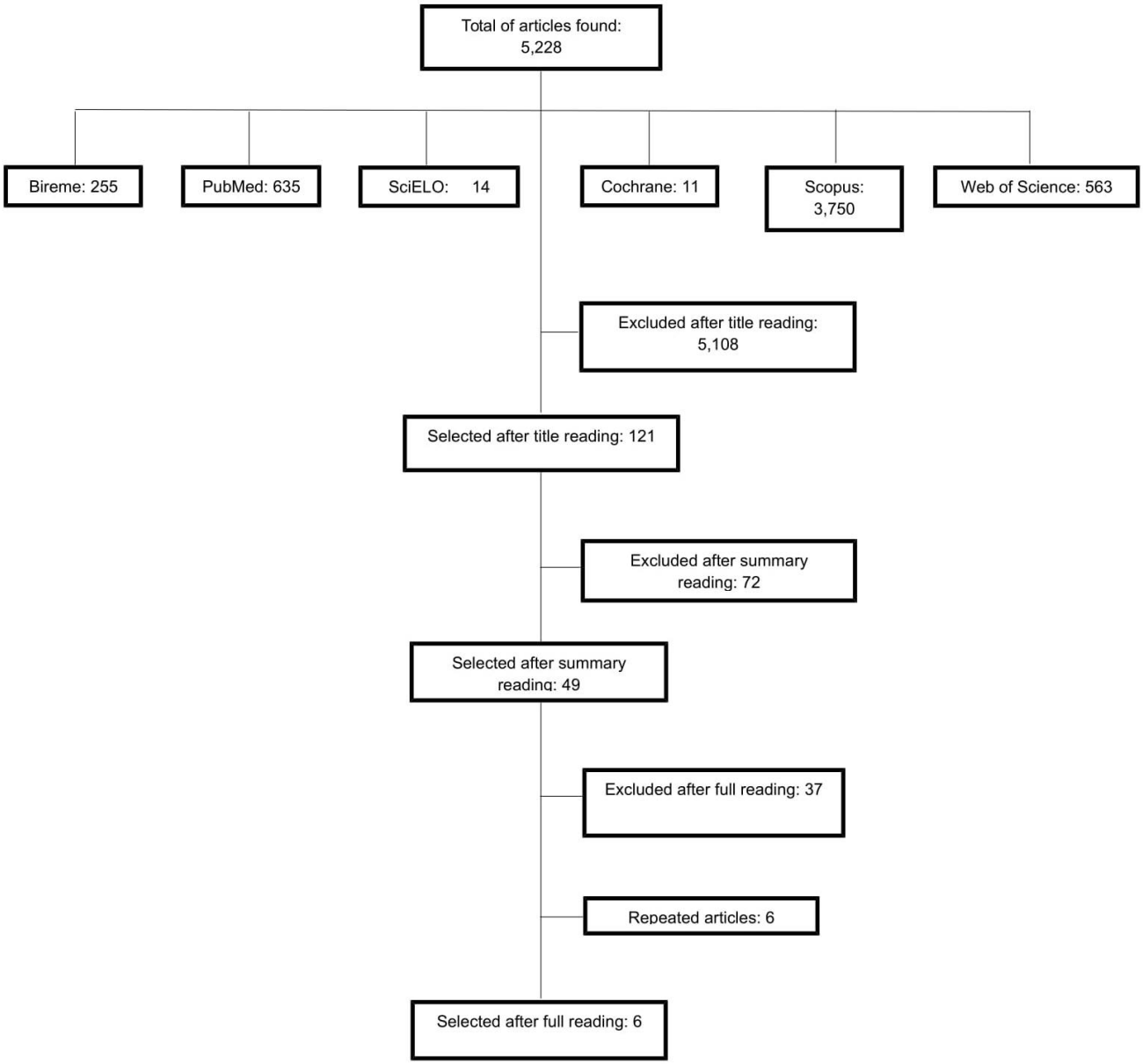

Figure 1. Flowchart of articles found, excluded and included in the review

RESULTS

After the completion of the crossings, a total 5,228 articles were found. After the application of the defined inclusion and exclusion criteria and subtraction of repeated publications listed in more than one database, a total six articles were selected.

With the exception of one study[11] published in Brazil, all other titles were published in the United States of America (USA)[12,13,15,16] and Australia[14].

The oldest study[14] selected dates back to 1992, while the latest[16] one dates from 2012. There were also two studies[12,15] published in 2008 and one[11] in 2009.

Except for four studies [11,14-16] that were published, respectively, in Pro-Fono Magazine, Australian Journal of Otolaryngology, Ear & Hearing, and Journal of Communication Disorders, the rest of the articles[12,13] were published in the Acoustical Society of America Magazine.

Regarding the sample size, the study with the largest sample size[16] had 69 participants, including implanted and not implanted individuals, while the article with the smallest sample size[12] evaluated only eight individuals.

When it comes to the vocal production evaluation method, the Brazilian publication[11] was the only one that evaluated its 25 individuals according to perceptual and acoustic analysis protocols. Two studies[15,16] evaluated the vocal production of its individuals only with a perceptual protocol. The oldest study[14] used a consonant production test for assessing vocal production,

Table 1. Characteristics of publications included in the integrative review

AUTHOR(S)	YEAR	PLACE OF PUBLICATION	PUBLICATION JOURNAL	SAMPLE SIZE	VOCAL PRODUCTION EVALUATION	AUDITORY PERCEPTION EVALUATION	MAIN FINDINGS	RECOMMENDATION GRADE/LEVEL OF SCIENTIFIC EVIDENCE
1. Coelho et al.[11]	2009	Brazil	Pró-Fono	25	Acoustic and perceptual evaluation	Speech perception test	Among the children with cochlear implants, those with better speech sounds perception skill have lower perceptual shifts in vocal quality.	C/4
2. Matthies et al.[12]	2008	USA	Acoustical Society of America	8	Acoustic evaluation	Speech perception test	CI users show decreased variability in the phonetic production as the experience with the implant increased.	B/3
3. Tye-Murray et al.[13]	1995	USA	Acoustical Society of America	23	Acoustic evaluation	Speech perception test	The results suggest that the experience with the CI may have led to an improvement in the production of some articulatory features.	B/3
4. Blamey et al.[14]	1992	AUS	Australian Journal Of Otolaryngology	9	Consonant production test	Speech perception test	Children showed continuous improvement over time in the perception and production of speech and language. Improvements tend to be faster for younger children.	B/3
5. Peng et al.[15]	2008	USA	Ear & Hearing	51	Perceptual evaluation	Sentences intonation recognition test	Performance levels in production and perception of sentence intonation tasks are moderately correlated for both implanted and non-implanted children groups.	C/4
6. Chin et al.[16]	2012	USA	Journal of Communication Disorders	69	Perceptual evaluation	Sentences intonation recognition test	Correlations between intelligibility, humor identification and classification scores were not significant, except for declarative sentences.	C/4

while other publications[12,13] preferred the acoustic analysis of voice and speech for evaluating the individuals.

Regarding the auditory perception evaluation, only two studies[15,16] performed a sentence intonation recognition test. All other articles[11-14] used different tests of speech perception.

The results suggest the existence of a positive relationship between vocal production and auditory perception in CI users, as well as indicate that implantation time has a positive influence in this relationship.

Regarding the level of scientific evidence, three publications[11,15,16] were classified as level 4 of scientific evidence and recommendation grade C. The other three studies assessed[12-14] achieved level 3 of scientific evidence and recommendation grade B.

Characteristics of the publications

The main findings of each study were considered below:

The first publication[11] is a quantitative, cross-sectional, observational case series study, which aimed to relate the speech perception abilities to the vocal characteristics of children with cochlear implants. Their findings point to the existence of a direct relationship between some vocal parameters, such as pitch and loudness, with speech perception abilities. It was observed that among children with cochlear implants, those with a better ability of speech sound perception have lower perceptual shifts in vocal quality.

Furthermore, it was observed that the higher the recognition of consonants, the higher the maximum frequency, standard deviation of the fundamental frequency and average intensity during connected speech, as well as fundamental frequency mean in the analysis of the /a/ vowel. These findings contrast with another study[18], which indicates a statistically significant reduction in fundamental frequency mean three months after implantation, as well as a minor deviation of this parameter in this population. Overall, the results show that there is a positive relationship between speech recognition and a good vocal production, as another author indicates[7].

The research conducted by Matthies et al.[12] is a longitudinal study, applying analysis of variance. They aimed to examine the context of changes in the production of /r/ variants before and after a cochlear implant, how these changes occurred and how this variability would behave when compared to non-implanted individuals. The authors started with the premise that, given the loss of auditory feedback, post-lingual deaf people tend to show greater acoustic variation in the production of /r/ variants in English than individuals with normal hearing. However, with the reestablishment of auditory feedback by CI, such variation tends to decrease over time. This assumption was reinforced, as the CI users showed decreased variability in production and phonetic approximation of the standard model as the experience with the implant increased, agreeing with previous findings reported in the literature[19].

The study conducted by Tye-Murray and Gilbert-Bedia[13] aimed to investigate the relationship between speech production and perception in young CI users. Its methodology consisted of two steps: a transversal moment, with 23 individuals, and longitudinal follow-up of 16 of the 23 initial individuals.

Their findings indicate that, in general, implant users produced the bilabial consonants /b/, /m/, /w/ with relatively fewer errors than the fricatives /s/ and /z/, which showed a high error rate, while the Pearson correlation test showed only one correlation: children with greater implantation time had better articulation points. In general, the results agree with previous literature[20] when they suggest that the experience with the CI may have led to an improvement in the production of some articulatory features as wells as nasality decreasing.

Blamey and his colleagues[14] discourse on some speech and language perception and production results of implanted children in order to illustrate the changes observed after implantation and the factors that may affect these changes. This is an intervention study that included nine individuals.

Closed-set speech perception tests were applied, as well as open-set tests, with and without lip reading aid. In a closed-set test, the individual has to choose the answer among given alternatives, as for an open-set test, alternatives are not presented. Closed-set tests are usually easier than open-set ones.

The results show that, at the most difficult level of speech perception (open-set tests without lip reading), five of the nine children performed well. On easier levels, such as open-set tests, performed with lip reading and closed-set tests without lip reading, there was no significant difference or above average performance.

Generally, children showed continuous improvement over time for perception and production of speech and language and these improvements tend to be faster for younger children, as suggested by previous publications[19,21].

The research led by Peng et al.[15] aimed to investigate implanted children's mastery of the perception and production of intonation features in speech skill, compared with non-implanted children in the same age group. This is an observational and cross-sectional study with correlation test application.

Their findings show that performance levels in production tasks and perception of sentence intonation are moderately correlated, for both groups. The authors suggest that these results may be related to the narrow range of distribution of the data accuracy in the identification of the features by the studied individuals.

The last publication[16] aimed to explore the relationship between the intelligibility of speech and prosodic production in cochlear-implanted children, comparing them with non-implanted children. This is a test application of an observational, cross-sectional nature, with correlation.

Its main findings show that the percentage of correct answers was higher for intelligibility than to prosody, and higher for children with normal hearing than for children with cochlear implants. It was also demonstrated that the correlations between intelligibility and humor identification and the score in the sentence classification task were not significant, except for declarative sentences. A previous study[20] suggests that the perception of intonation variations in speech tends to improve as the experience with CI increases.

This publication stands out as one of the pioneers in the study of vocal emotion production of implanted children and provides results similar to other literature findings[20], which

point out that the speech of implanted children is significantly less intelligible than the normal hearing children's speech.

Regarding the level of scientific evidence, it was not possible to find any studies with level 1 or recommendation grade A, which can be explained by the fact that it is not possible, in this population, to conduct studies commonly classified as 1/A, such as randomized clinical trials.

There is a great lack of publications relating auditory perception and speech production CI users, which may be related to the difficulties of studying this population. This gap is even greater when it comes to adult population, considering that, of the six studies analyzed, five focused on the children and young.

CONCLUSION

The findings point to the existence of a positive relationship between vocal production and auditory perception in CI users, and indicate that the implantation time has a positive effect in this relationship, but none of the few publications found received Level 1 of scientific evidence or recommendation grade A, which is related to the methodological approach applicable with this study object. Still, there is a need for greater scientific production in the field, with greater methodological accuracy.

REFERENCES

1. Martins MBB, Lima FVF, Santos RC Jr, Santos ACG, Barreto VMP, Jesus EPF. Implante coclear: Nossa experiência e revisão de literatura. Int Arch Otorhinolaryngol. 2012;16(4):476-81. PMid:25991976.
2. Pinho SMR. Fundamentos em fonoaudiologia: tratando os distúrbios da voz. Rio de Janeiro: Guanabara Koogan; 2003. p. 3-40.
3. Frederigue NB, Bevilacqua MC. Otimização da percepção da fala em deficientes auditivos usuários do sistema de implante coclear multicanal. Rev Bras Otorrinolaringol. 2003;69(2):227-33. http://dx.doi.org/10.1590/S0034-72992003000200013.
4. Silva RCL, Araújo SG. Os resultados do implante coclear em crianças portadoras de Neuropatia Auditiva: revisão de literatura. Rev Soc Bras Fonoaudiol. 2007;12(3):252-7. http://dx.doi.org/10.1590/S1516-80342007000300014.
5. Strøm-roum H, Laurent C, Wie OB. Comparison of bilateral and unilateral cochlear implants in children with sequential surgery. Int J Pediatr Otorhinolaryngol. 2012;76(1):95-9. PMid:22075133. http://dx.doi.org/10.1016/j.ijporl.2011.10.009.
6. Wie OB. Language development in children after receiving bilateral cochlear implants between 5 and 18 months. Int J Pediatr Otorhinolaryngol. 2010;74(11):1258-66. PMid:20800293. http://dx.doi.org/10.1016/j.ijporl.2010.07.026.
7. Lenden JM, Flipsen P Jr. Prosody and voice characteristics of children with cochlear implants. J Commun Disord. 2007;40(1):66-81. PMid:16765979. http://dx.doi.org/10.1016/j.jcomdis.2006.04.004.
8. Buarque LFSFP, Brazorotto JS, Cavalcanti HG, Lima Júnior LRP, Lima DVSP, Ferreira MAF. Desempenho auditivo ao longo do tempo em usuários de implante coclear com perda auditiva pós-lingual. Audiol Commun Res. 2013;18(2):120-5. http://dx.doi.org/10.1590/S2317-64312013000200010.
9. Hoshino ACH, Cruz DR, Goffi-Gomez MVS, Befi-Lopes DM, Matas CG, Fortunato-Tavares TM, et al. Evolução audiométrica em usuários de implante coclear multicanal. Rev CEFAC. 2013;15(2):297-304. http://dx.doi.org/10.1590/S1516-18462012005000037.
10. Pomaville FM, Kladopoulos CN. The effects of behavioral speech therapy on speech sound production with adults who have cochlear implants. J Speech Lang Hear Res. 2013;56(2):531-41. PMid:23275412. http://dx.doi.org/10.1044/1092-4388(2012/12-0017).
11. Coelho ACC, Bevilacqua MC, Oliveira G, Behlau M. Relação entre voz e percepção de fala em crianças com implante coclear. Pró-Fono R Atual Cient. 2009;21(1):7-12.
12. Matthies ML, Guenther FH, Denny M, Perkell JS, Burton E, Vick J, et al. Perception and production of /r/ allophones improve with hearing from a cochlear implant. J Acoust Soc Am. 2008;124(5):3191-202. PMid:19045803. http://dx.doi.org/10.1121/1.2987427.
13. Tye-Murray N, Spencer L, Gilbert-Bedia E. Relationships between speech production and speech perception skills in young cochlear-implant users. J Acoust Soc Am. 1995;98(5 Pt 1):2454-60. PMid:7593929. http://dx.doi.org/10.1121/1.413278.
14. Blamey PJ, Dawson PW, Dettman SJ, Rowland LC, Brown AM, Busby PA et al. Speech perception, production and language results in a group of children using the 22 electrode cochlear implant. Aust J Otolaryngol. 1992;1(2):105-109.
15. Peng SC, Tomblin JB, Turner CW. Production and perception of speech intonation in pediatric cochlear implant recipients and individuals with normal hearing. Ear Hear. 2008;29(3):336-51. PMid:18344873. http://dx.doi.org/10.1097/AUD.0b013e318168d94d.
16. Chin SB, Bergeson TR, Phan J. Speech intelligibility and prosody production in children with cochlear implants. J Commun Disord. 2012;45(5):355-66. PMid:22717120. http://dx.doi.org/10.1016/j.jcomdis.2012.05.003.
17. CEBM: Centre for Evidence-Based Medicine. Levels of evidence [Internet]. Oxford; 2011 [cited 2013 Jun 22]. Available from: http://www.cebm.net/ocebm-levels-of-evidence/
18. Hamzavi J, Deutsche W, Baumgartner WD, Bigenzahn W, Gstoettner W. Short-term effect of auditory feedback on fundamental frequency after cochlear implantation. Audiology. 2000;39(2):102-5. PMid:10882049. http://dx.doi.org/10.3109/00206090009073060.
19. Perkell JS, Guenther FH, Lane H, Matthies M, Perrier P, Vick J, et al. Planning and auditory feedback in speech production. In: 4th International Speech Motor Conference Nigmegen; 2001; Netherlands. Proceedings. Netherlands; 2001. p. 5-11.
20. Chin SB, Tsai PL, Gao S. Connected speech intelligibility of children with cochlear implants and children with normal hearing. Am J Speech Lang Pathol. 2003;12(4):440-51. PMid:14658996. http://dx.doi.org/10.1044/1058-0360(2003/090).
21. Kunisue K, Fukushima K, Nagayasu R, Kawasaki A, Nishizaki K. Longitudinal formant analysis after cochlear implantation in school-aged children. Int J Pediatr Otorhinolaryngol. 2006;70(12):2033-42. PMid:16939694. http://dx.doi.org/10.1016/j.ijporl.2006.07.012.

Author contributions

HRSC participated in this study design and drafting, data collection, analysis and data interpretation; MCL, JAL and LFM participated in the conception, design and study review.