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Speech production of children and adolescents from an auditory rehabilitation program

Produção da fala de crianças e adolescentes de um programa de reabilitação auditiva

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ABSTRACT

Purpose: To characterize the speech production of children and adolescents from an auditory rehabilitation program who use hearing aids (HA) or cochlear implant (CI). **Methods:** Cross-sectional observational study. Speech samples from 15 participants of a hearing rehabilitation program were analyzed through the phonology test of the ABFW Test and spontaneous conversation, which were adapted from the Protocol for the Evaluation of Voice in Subjects with Hearing Impairment. The Wilcoxon test was used to compare the Percentage of Consonants Correct (PCC) and the Percentage of Consonants Correct–revised (PCC-r) indexes of the phonology test, and the Mann-Whitney test was used to compare these indexes to the degrees of intelligibility of spontaneous conversation. The variability of production of the phonemes of the phonology tests was also analyzed. **Results:** There was a mild deviation in the PCC and PCC-r indexes for the phonology tests, with higher scores for the PCC-r. Participants with averages greater than 85% achieved "Good" intelligibility, and participants with averages between 85% and 50% had "Regular/Insufficient" intelligibility. The HA users did not properly produce the phonemes /s/, /z/, /ʒ/ /ɲ/, /l, /ɾ/, the archiphoneme /S/, and the archiphoneme /R/. The CI users did not properly produce the phonemes /ɾ/ and the archiphoneme /R/. **Conclusion:** The group had a mild deviation in the PCC and PCC-r indexes, with higher means when the distortion was considered correct. Participants with "Good" intelligibility had higher PCC and PCC-r scores. HA users did not produce fricative phonemes properly. There were productions with a social and regional linguistic variation.

Keywords: Cochlear implants; Hearing aids; Hearing loss; Speech intelligibility; Child; Adolescent

RESUMO

Objetivo: caracterizar a produção da fala de crianças e adolescentes usuários de aparelho de amplificação sonora individual (AASI) ou implante coclear (IC) de um programa de reabilitação auditiva. **Métodos:** estudo observacional transversal. Foram analisadas amostras de fala de 15 participantes de um programa de reabilitação auditiva, que consistiam na prova de fonologia do ABFW (ABFW - Teste de Linguagem Infantil nas Áreas de Fonologia, Vocabulário, Fluência e Pragmática) e na fala espontânea, adaptada do Protocolo de Avaliação de Voz do Deficiente Auditivo. Foi aplicado o teste de Wilcoxon para comparar os índices de Porcentagem de Consoantes Corretas (PCC) e Porcentagem de Consoantes Corretas revisado (PCC-r) das provas de fonologia e o teste de Mann-Whitney para comparar os referidos índices, em relação aos graus de inteligibilidade da fala espontânea. Também foi analisada a variabilidade de produção dos fonemas das provas de fonologia. **Resultados:** verificou-se desvio leve nos índices de PCC e PCC-r para as provas de fonologia, com escores superiores para o PCC-r. Os participantes com médias maiores que 85% alcançaram inteligibilidade "Boa" e participantes com médias entre 85% e 50% apresentaram inteligibilidade "Regular/Insuficiente". Os usuários de AASI não produziram adequadamente os fonemas /s/, /z/, /ʒ/ /ɲ/, /l, /ɾ/, arquifonema /S/ e arquifonema /R/ e os usuários de IC, os fonemas /ɾ/ e arquifonema /R/. **Conclusão:** o grupo estudado apresentou desvio leve nos índices de PCC e PCC-r, com médias superiores, quando considerada a distorção como acerto. Participantes com inteligibilidade "Boa" apresentaram maiores escores de PCC e PCC-r. Usuários de AASI não produziram fonemas fricativos adequadamente. Foram observadas produções com variação linguística social e regional.

Palavras-chave: Implantes cocleares; Auxiliares de audição; Perda auditiva; Inteligibilidade da fala; Criança; Adolescente

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INTRODUCTION

Children and adolescents with hearing loss may present alterations in speech production due to decrease or absence of auditory feedback, which is essential for controlling speech characteristics[1].

Currently, electronic devices such as hearing aids (HA) and cochlear implants (CI) have provided access to speech sounds for this group of children and adolescents[2,3].

Using hearing aids and CI alone does not allow to acquire spoken language; therefore, Speech-Language Pathology intervention is necessary for a hearing rehabilitation program that enables the development of spoken language, in partnership with the family[2].

Different elements are important for understanding between people communicating in spoken language to be reached. Among them, intelligibility plays an important role in oral communication effectiveness, as it involves a series of aspects, including mechanisms of speech production, such as phonation, articulation, resonance, and prosody, which are fundamental for speech clarity[1,4].

Studies have shown that children and adolescents with hearing loss may present difficulties in speech production, thus influencing the element of intelligibility[1,5]. In addition, factors such as auditory access through electronic device, perception of speech sounds and mastery of language can influence results related to speech intelligibility in children and adolescents who use hearing aids or CI[6-8].

In the literature, studies addressing speech production of hearing aid or CI users have proposed the use of the Percentage of Consonants Correct (PCC) and the Percentage of Consonants Correct – revised (PCC-r) indices. Such indices refer to objective parameters of speech assessment, capable of demonstrating the severity of the phonological disorder, with result expressed as percentage, calculated by dividing the correct consonants by the total consonants in the sample, multiplied by 100. The severity criterion is established based on the percentage of correct answers as follows: more than 85% of correct consonants – mild deviation; between 85% and 65% – mild-moderate; between 65% and 50% – moderate-severe, and below 50% correct consonants – severe deviation. The PCC and PCC-r indices differ in terms of analysis: for the PCC, omissions, substitutions, and distortions are considered errors, while for the PCC-r, distortions are excluded from error classification[9,10].

Research has also applied scales to assess the speech production in the studied population, in which numbers corresponding to different levels of intelligibility are assigned[6-8].

It is worth highlighting the importance of assessing speech production in the sense of understanding and characterizing the changes that may be involved in the oral communication process and assisting in speech-language pathology conducts.

Thus, this study aimed to characterize the speech production of children and adolescents using hearing aids or cochlear implants in the context of a hearing rehabilitation program.

METHODS

This cross-sectional observational study was carried out by analyzing a database of the Laboratory of Acoustic Analysis of São Paulo State University, Marília Campus. The research was approved by the Research Ethics Committee of this institution (Report No. 3,019,753). Participants and/or guardians signed the Assent Term and/or the Free and Informed Consent Term. The total number of participants in the database was included in this study.

Speech samples from 15 children and adolescents were analyzed, seven males and eight females, with moderate (n= 1), severe (n= 5) and profound (n= 9) bilateral sensorineural hearing loss. All participants were users of CI (n=9) or bilateral hearing aids (n=6) aged between 6 and 17 years who were participating or had participated in a hearing rehabilitation program.

Participants were chronologically aged between 6 years and 6 months and 17 years and 3 months (average of 12 years and 6 months). The diagnosis of hearing loss was performed between 1 month and 6 years and 10 months of age (mean 2 years and 2 months). The devices (HA or CI) were adapted between 6 months and 8 years and 11 months (mean 3 years and 3 months), as well as the time of sensory deprivation. The minimum time of device use was set at four years and six months, with a maximum of 14 years and three months (average of nine years and two months).

Regarding the participants' speech perception, the group reached an average of 88.86% for recognition of phonemes[11], ranging between 54.87% and 100%. As for word recognition[11], an average score of 77.33% was observed, with a minimum of 30% and a maximum of 100%. Regarding sentences[12,13], an average score of 76.93% was observed, varying between 34% and 100%.

A Mann-Whitney test ($p<0.005$) comparing the aforementioned demographic data for the degree of hearing loss and device used revealed homogeneity in the the group as a whole.

Children and adolescents who had other impairments associated with hearing loss and/or diagnosis of laryngeal alteration were excluded.

The sample consisted of the phonetic transcription based on the International Phonetic Alphabet – IPA[14] of the phonology tests (imitation and naming) of the ABFW – Child Language Test in the areas of Phonology, Vocabulary, Fluency and Pragmatics[15], and spontaneous conversation. The tests had an average duration of two minutes, with the theme "tell me about a special day for you" or children's stories, adapted from the Protocol for the Evaluation of Voice in Subjects with Hearing Impairment – PEV-SHI[16].

These samples were recorded in an acoustically treated room on a high-reliability digital recorder MARANTZ, model PMD660, configured for single-channel recording, at a sampling rate of 44 kHz and 16 bits of resolution, Sennheiser microphone, model e835, positioned at 45 degrees and five centimeters away from the participants' mouths.

A perceptual-auditory judgment of the samples was performed by three judges with experience in speech assessment, individually, and the analysis with the highest intra-judge agreement was selected, using the Kappa Agreement Index (Kappa: 1.000; $p<0.001$).

For the phonology test, the Percentage of Consonants Correct[9] and Percentage of Consonants Correct – revised[17] were calculated.

Likert scale score was applied for spontaneous conversation, according to a previous study, as follows[18]:

1 – Insufficient (incomprehensible): when most of the words were not understandable and the child/adolescent had difficulty understanding the main topic of the message;

2 – Fair (poorly understandable): when the child/adolescent could understand at least half of the words and the main topic of the message, and

3 – Good (understandable): when it was possible to understand practically all the words and the content of the message.

Wilcoxon statistical test was applied to compare the PCC and PCC-r indices, also in addition to the Mann-Whitney test to compare the PCC and PCC-r indices in relation to the degrees of intelligibility of spontaneous conversation. For these tests, a significance index of 5% ($p< 0.005$) was admitted. Furthermore, the the variability in the production of phonemes of the naming and imitation tests was analyzed considering the percentage of correct answers, distortions, and substitutions/omissions of consonants. The phonemes produced with more than 75% of correct answers were considered adequate.

RESULTS

Table 1 presents the comparison between the Percentage of Consonants Correct and the Percentage of Consonants Correct – revised.

The imitation test ($p= 0.028$) showed a statistically significant difference between the averages of the PCC index (86.74%) and PCC-r (88.94%). There was also a statistically significant difference between the averages of the PCC index (85.89%) and PCC-r (88.22%) in the naming test ($p= 0.011$).

For both tests (imitation and naming), the PCC and PCC-r indices of the participant group were above 85% (mild deviation).

Table 2 presents the comparison between the PCC and PCC-r indices in relation to the degrees of intelligibility of spontaneous conversation.

The results showed a statistically significant difference between the PCC and PCC-r indices regarding the degrees of intelligibility of spontaneous conversation. In the imitation and naming tests, the participants were assigned with the following intelligibility degrees: "Good" for averages of PCC and PCC-r above 85% (mild deviation) and "Fair/Insufficient" for averages between 85% and 50% (mild-moderate deviation and moderate-severe).

Table 3 describes the percentages of correct answers, distortions, substitutions/omissions of consonants, for the naming and imitation tests. Substitutions and omissions were grouped in the same category, as they are considered errors in both indices (PCC and PCC-r). In the occurrence of more than 75% of correct phonemes, it was considered adequate. Thus, all phonemes that reached a score above 75% of correct answers are not shown in the table.

The naming test indicated that hearing aid users obtained percentages of correct answers for the fricative phonemes /s/ (52.38%), /z/ (58.33%) and /ʒ/ (50%) with higher frequency of distortion in the phoneme /s/ (11.90%) and substitutions/omissions in the phoneme /ʒ/ (50%).

The nasal phoneme /ɲ/ presented 66.66% of correct answers, with percentages of distortions and substitutions/omissions of 16.66%. 58.33% of correct answers were verified for the consonant /ʎ/, with 41.66% of substitutions/omissions.

The archiphonemes /R/ and /S/ presented 72.33% and 50% of correct answers, respectively, with 27.77% of substitutions/omissions for the archiphoneme /R/ and 8.33% of distortions and 41.66% of substitutions/omissions for the archiphoneme /S/.

The CI users could not reach 75% of correct answers in only 2 phonemes of this test: /ʎ/, with 72.22%, with 27.77% of substitutions/omissions and archiphoneme /R/, with 70.37% and distortion in 7.40%.

In the imitation test, hearing aid users obtained a percentage of correct answers for the fricative phonemes /s/ (53.33%), /z/ (50%), and /ʒ/ (72.22%), with percentages of distortions in the phoneme /s/ (20%) and substitutions/omissions in the phoneme /z/ (33.33%).

In the nasal phoneme /ɲ/, 50% of correct answers and 50% of substitution/omission were obtained.

The percentages of correct answers for /l/ were 70.83% and for /ʎ/, 66.66%, with 33.33% of substitution/omission in the phoneme /ʎ/.

For the archiphoneme /R/, 50% of correct answers were verified, with substitution/omission of 44.44% and, for the archiphoneme /S/, 58.55% of correct answers, with a distortion of 5.55%.

In the imitation test, CI users reached more than 75% of correct answers for all phonemes.

Table 1. Comparison of the Percentage of Consonants Correct and Percentage of Consonants Correct - revised

Test	Average (%)	Standard Deviation	n	p-value
PCC Imitation	86.74	13.69	15	0.028*
PCC-r Imitation	88.94	10.79	15	
PCC Naming	85.89	18.74	15	0.011*
PCC-r Naming	88.22	16.57	15	

Wilcoxon Test; *Significant values ($p<0.05$)

Subtitle: PCC = Percentage of Consonants Correct; PCC-r = Percentage of Consonants Correct - revised; n = number of participants

Table 2. Comparison of the Percentage of Consonants Correct and Percentage of Consonants Correct- revised in relation to the degrees of intelligibility of spontaneous conversation

Test	Average (%)	Standard Deviation	Degree of Intelligibility	n	p-value
PCC Imitation	93.52	6.28	Good	11	0.003*
	68.09	10.53	Fair/Insufficient	4	
PCC-r Imitation	94.10	5.24	Good	11	0.004*
	74.73	9.21	Fair/Insufficient	4	
PCC Naming	95.39	4.62	Good	11	0.002*
	59.74	18.03	Fair/Insufficient	4	
PCC-r Naming	96.46	3.94	Good	11	0.004*
	65.59	17.25	Fair/Insufficient	4	

Mann-Whitney test; *Significant values ($p<0.05$)

Subtitle: PCC = Percentage of Consonants Correct; PCC-r = Percentage of Consonants Correct - revised; n = number of participants

Table 3. Percentage of correct answers, distortions and substitutions/omissions of the consonants that obtained less than 75% of correct answers for the naming and imitation tests

Device	Phoneme	Naming (%)			Imitation (%)		
		Correct answer	Distortion	Substitution/ Omission	Correct answer	Distortion	Substitution/ Omission
HA	s	52.38	11.90	35.71	53.33	20.00	26.66
	z	58.33	4.16	37.50	50.00	16.66	33.33
	ʒ	50.00	0	50.00	72.22	0	27.77
	ɲ	66.66	16.66	16.66	50.00	0	50.00
	l	75.00	4.16	20.83	70.83	16.66	12.50
	ʎ	58.33	0	41.66	66.66	0	33.33
	Archi/R/	72.33	0	27.77	50.00	5.55	44.44
	Archi/S/	50.00	8.33	41.66	58.33	4.16	37.50
CI	ʎ	72.22	0	27.77	88.88	0	11.11
	Archi/R/	70.37	7.40	22.22	81.48	0	18.51

Subtitle: HA = Hearing Aids; CI = Cochlear Implant; Archi/R/ = Archiphoneme/R/; Archi/S/ = Archiphoneme/S/

DISCUSSION

This study aimed to characterize the speech production of children and adolescents using individual hearing aids or cochlear implants in the context of a hearing rehabilitation program.

The group analyzed in the research presented results of the PCC and PCC-r indices in the imitation and naming tests corresponding to mild phonological disorder (Table 1). Studies addressing the PCC of children with hearing loss in the age group from 3 to 11 years, using the ABFW, have found moderate-severe phonological disorder for users of bilateral hearing aids and mild-moderate phonological disorder in children who used bilateral hearing aids or unilateral CI[19,20].

The results also showed a statistically significant difference between the analysis of PCC and PCC-r, both in the imitation and the naming test, that is, the scores were higher for the index that considers distortions as correct – PCC-r (Table 1). The literature reports that distortion is one of the manifestations observed in the speech production of people with hearing loss, which can be minimized with early access to auditory feedback. Studies have shown that early diagnosis and intervention allow to reduce the impact of hearing loss on the development of speech production[1,19,21,22].

A comparison of the PCC and PCC-r indices for the degrees of intelligibility of spontaneous conversation revealed a statistically significant difference, demonstrating that the participants who obtained a "Good" degree of intelligibility had higher PCC and PCC-r scores than the participants of a "Fair/Insufficient" degree of intelligibility (Table 2).

In the context of the typical development of hearing and language[15], acquisition of Portuguese language sounds is complete up to 7 years of age,. In children and adolescents with hearing loss, different factors can impact listening skills and oral communication due to the heterogeneous nature of the population in terms of demographics[23].

On the one hand, in the studied sample, the diagnosis of hearing loss and access to speech sounds occurred from 2 years and 2 months of age (diagnosis) and 3 years and 3 months of age (device adaptation). Studies have shown that children and adolescents with hearing loss achieve speech production equivalent to hearing peers when diagnosis and intervention occur early[22,24].

On the other hand, it is also worth emphasizing that the participants used technological devices to access speech sounds and participated in a hearing rehabilitation program, enabling those with higher PCC and PCC-r scores to reach a "Good" degree of speech intelligibility. These findings agree with research highlighting the impact of these factors on speech production[6,24,25].

It is noteworthy that even with technological advances in relation to hearing aids and CI, speech production can be a challenge for children with hearing loss. In this sense, the literature indicates the importance of auditory rehabilitation programs emphasizing the improvement of speech production[26].

An analysis of the results of production variability showed that most phonemes reached percentages from 75%, being considered adequate (Table 3)[15]. Only children and adolescents using hearing aids had scores below 75% for the fricative phonemes /s/, /z/, and /ʒ/ and archiphoneme /S/. In Brazilian Portuguese, fricative phonemes have the lowest intensities and range higher frequencies. The phonemes /s/ and /z/ are above 4500 Hz, reaching 8000 Hz, while the phonemes /ʃ/ and /ʒ/ range between 2500 Hz and 6000 Hz[27]. The auditory perception of these phonemes is a challenge for hearing aid users, and can impact speech production[3].

The phonemes /f/ and /v/ were the most adequately produced and the alveolar /s/ and /z/ presented more substitutions, omissions and distortions, followed by the palatal /ʃ/ and /ʒ/. These findings corroborate a study showing that forward fricative phonemes were more correctly produced and also that distortion errors were more significant for /s/ and /z/[5].

Other phonemes had scores below 75%, such as /ɲ/, /l, and /ʎ/ and archiphoneme /R/. An analysis of the words containing these phonemes indicated the possibility of social and regional linguistic variation in speech production, for example, /paʎaso/ – /payaso/ ("clown" in Portuguese)[28]. Such variation can also be found in situations of deletion of the archiphoneme /R/, for example, /tratoR/ ("tractor" in Portuguese) – /trato/, a trend in several regions of Brazil[29,30].

Another aspect to be considered is the mastery of vocabulary in oral communication, that is, words that are not part of the lexicon may be produced wrongly, such as /vinho/ ("wine" in Portuguese).

Through different analyses, our results enable to understand the speech production of a group of children and adolescents with hearing loss, users of hearing aids or CI, which may be

important tools for monitoring this population in the auditory rehabilitation process. Further studies should be developed addressing groups of participants with hearing loss with other demographic characteristics rather than the sample herein.

CONCLUSION

The studied group showed a mild deviation in the PCC and PCC-r indices and the means were higher when distortion was considered as correct (PCC-r).

The "Good" degree of intelligibility was obtained by children and adolescents with hearing loss upon averages of PCC and PCC-r above 85%.

Most phonemes were produced properly by the participants, except for fricatives in hearing aid users, and phonemes with the possibility of social and regional linguistic variation.

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