Research Paper

Phonological Measurement Indices in Hearing Impaired Children: Cochlear Implantation and Hearing Aids

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ABSTRACT

Objectives: Phonological deficits are expected in people with hearing impairment because the auditory system is the basis for language acquisition. This study aims to compare phonological measurement indices in children with cochlear implants (CI), hearing aids, and normal hearing.

Methods: This cross-sectional study included 100 Persian-speaking children aged 3-6 years, including 25 children with severe hearing loss with bilateral hearing aids, 25 with unilateral CI, and 50 with normal hearing. Children with hearing aids and children with CI were selected by convenience sampling from the Naghma and Parvaneha Rehabilitation Center for hearing-impaired children in Mashhad City, Iran. The phonological subtest of the Persian version of the diagnostic evaluation of articulation and phonology (DEAP), which includes the two tasks of picture naming and picture description was performed, and the phonological indices, including phonological mean length of utterance (PMLU), phonological whole- word proximity, proportion of whole-word correctness (PWC), percentage of consonants correct, and percentage of vowel correct (PVC), were calculated. The performances of participants in the three groups on each index were compared in picture naming and description tasks. Also, the performance of the participants in the two tasks was compared in each group.

Results: A significant difference was observed in the mean scores of all phonological indices among the three groups (P<0.001), with children with normal hearing performing better than cochlear-implanted and hearing-impaired children, and cochlear-implanted children also had better performance than hearing children. Also, the difference in the mean of all phonological indices in the two tasks was only significant in the group with hearing aids (P<0.05).

Discussion: Children with cochlear implants, despite having a new and more useful technology than hearing aids, still have problems with phonemic accuracy, especially in whole-word indices, compared to children with normal hearing. Also, the difference in indicators between the two tasks in the group with hearing aids confirms the influence of phonetic context, which should be considered when evaluating and treating phonological deficits in these children.

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Highlights

- The methods of analysis of children's phonological development are explained.
- The influence of phonetic context on phonological evaluations is discussed.
- It considers the effect of word length on phonological evaluations.
- Phonological measurement indices are discussed in normal children, children with hearing aids, and children with CI.
- Phonological measurement indices are evaluated in children with CI, hearing aids, and normal hearing.

Plain Language Summary

This study showed that children with normal hearing had better pronunciation skills than cochlear-implanted and hearing-impaired children, and cochlear-implanted children also had better pronunciation skills than children with hearing aids. The results of the present study showed that the pronunciation features of hearing-impaired children are affected due to their deprivation of the sense of hearing and require a detailed speech therapy program in this area. Using a cochlear implants (CI) device has a greater effect on improving the performance of hearing-impaired children in sound pronunciation.

Introduction

Early listening experiences play a crucial role in the acquisition and correct production of the sounds of the native language [1]; therefore, even slight deficits in the sense of hearing can result in problems in the acquisition of various areas of language particularly, phonological skills [2]. Given the prevalence of hearing loss, estimated at 1 to 9 per thousand worldwide, and its negative impact on the development of speech and language skills, it is valuable to conduct studies focusing on the phonological development of affected children [3]. Moeller et al. reported that hearing-impaired children have poor consonant and syllabic development, which can affect the impact of a child's first words [4]. Children with hearing impairment produce fewer multi-syllable consonant-vowel strings [5].

Many methods analyze children's phonological development. These include the order of acquisition of speech sounds [6], the number of phonemes in a child's phonetic repertoire [7], and suppression of phonological processes [8]. Most experimental research focuses on the process of development and acquisition of speech sounds or different segments of the word [9-11], including the percentage of consonants correct (PCC) index, which deals with the correctness of consonants [12], and the percentage of vowel correct (PVC), which refers to the estimation of the percentage of correctly pronounced vowels in speech. However, from a theoretical perspective, children's ability to correct word production has been identified as a crucial aspect of phonological development. Ingram proposed the phonological mean length of utterance (PMLU) index as a phonological measurement method to assess the phonological complexity of words in speech [13]. This index is calculated by considering word length and PCC [14]. The critical difference between this index and other indices is that it focuses more on consonants to show that children's errors are more likely to occur with these [15].

Children have different types of phonological errors, each affecting speech intelligibility differently. The PMLU index is more sensitive to omission errors than the PCC index. With PCC, no difference is observed between omission and substitution errors, whereas with PMLU, these two error types are calculated differently [14]. Ingram explains the phonological index of whole-word proximity (PWP), an indirect index of word intelligibility that demonstrates the relationship between a child's correct production and standard production. The PWP index has maximum values when the target word and the word produced by the child match [16].

The proportion of whole-word correctness (PWC) is another index of phonological development at the word level [17]. This is a simple measure to evaluate the overall accuracy of children's productions compared to adults' productions [16]. Despite PVC and PCC, whole-word phonological measures, such as PMLU, PWP, and PWC, consider the production accuracy of sounds at the

word level and do not consider speech sounds individually. Therefore, these measures can determine a child's phonological abilities at different stages of growth and can be used to assess progress toward treatment goals. The whole word indices presented by Ingram have been applied to normal children [18], bilingual children [19, 20], longitudinal growth development [9], premature children with production problems [21], and hearing-impaired children [14, 22, 23].

Consistent with the study of children's phonological development based on whole-word phonological indices, Taelman et al. found that Dutch children's PMLU scores increased with age, which was predictable because children use more complex words. In addition, the authors argued that the PMLU value reflects phonological-morphological development [24]. Consistent with Ingram, PMLU reference values vary across languages due to the cross-linguistic diversity of phonological characteristics [16]. Maggie et al. concluded that the PWP and PMLU indices can be used to assess and appropriately select words for intervention in children younger than three years old [9].

Some studies have investigated phonological development in hearing-impaired children. Zanichelli found that the PCC index was higher in children with normal hearing than in children with hearing loss in all three tasks: Naming pictures, imitation, and spontaneous speech [25]. Schauwers et al. concluded that the performance of Dutch children with cochlear implants (CI) was weaker on whole-word phonological indices than that of their normal-hearing peers. He also found that earlier implantation in the first year of life led to higher PMLU scores [26]. These results confirm the findings of Moeller et al. who showed that children with hearing loss experience a delay in the development of consonants and syllables, which can hinder the learning of first words [4].

Since the correct production of consonants and vowels can affect speech intelligibility, Yi conducted a study in which the speech intelligibility of the spontaneous speech of 21 children with mild to profound hearing loss was examined and assessed by 46 adults. The results showed that hearing-impaired children's PVC and PWP indices increased with age. Finally, data analysis showed a significant correlation between whole-word phonological measures and speech intelligibility, and the PCC, PVC, PMLU, and PWP indices were strong predictors of speech intelligibility [23].

Despite the crucial role that whole word-level indices play in determining the development of phonological skills, the differentiation of various phonological disorders [27, 28], and the development of intervention plans for hearing-impaired children and other children with special needs, studies on phonological skills have mainly focused on phonological development at the consonant and vowel levels. Therefore, this study compared the scores of 3-6-year-old Persian-speaking children with hearing loss with their typically developing peers, including PMLU, PWP, PWC, PCC, and PVC.

Materials and Methods

Participants

This cross-sectional study included 100 Persian-speaking children aged 3-6 years, including 25 children with severe hearing loss and hearing aids, 25 with CI, and 50 with normal hearing. Children with hearing aids and CI were selected by convenience sampling from the Naghma and Parvaneha Rehabilitation Center for hearing-impaired children in Mashhad City, Iran. The participants were matched based on age and sex. Children with normal hearing were also selected from kindergartens in Mashhad City in such a way that they were matched with each of the children in the disorder groups in terms of age and sex, and they also met the inclusion criteria.

The inclusion criteria for children with normal hearing included Persian-speaking and monolingual children aged 3-6 years, with normal hearing, no history of otitis media, no history of drug consumption, no co-morbidities, normal development of speech and language skills based on the reports of parents and teachers, the health records available in kindergarten, and the evaluation of the researcher during communication with the child. The inclusion criteria for hearing impaired children included the presence of bilateral sensorineural hearing loss, having bilateral hearing aids for children with hearing aids, unilateral CI for children with CI, at least 1 year has passed since the use of CI and hearing aids, children with hearing aids with severe hearing loss, the occurrence of hearing loss before the age of language learning (before the age of 3), using a hearing aid before the age of language learning (before the age of 3), age range of 3 to 6 years, the history of rehabilitation in the field of hearing training and speech therapy immediately after receiving the hearing aid, not suffering from comorbidities, normal intelligence, being Persian-speaking and monolingual according to the information available in the hearing loss center. The exclusion criteria included the child's non-cooperation, damage to the hearing aid, concurrent rehabilitation, and the occurrence of any symptoms indicating that the child did not use the hearing aid.

Procedures

After selecting each subject and obtaining informed consent from their parents, the phonological subtest of the diagnostic evaluation of articulation and phonology-Persian version (DEAP), called the Persian phonological test, was administered to each participant [29]. The validity and reliability of this test have been determined by Zarifian et al. and the test was administered to each participant [29]. The phonological subtest of the DEAP version test includes two parts: Picture naming and description. The picture-naming task included 54 pictures, all with the target consonant in two initial and final positions and all vowels in their syllabic construction. Among the words assigned to this part were 31 monosyllabic items, 18 two-syllable items, four three-syllable items, and one four-syllable item, and 29 words had final consonant clusters. The picture description task included three animated pictures with 14 target words from the picture naming task.

The test was performed after preparing and establishing proper communication with participants in a proper room regarding noise, light, temperature, and ventilation. During the test, the examiner sat in front of the child, and pictures were placed on the table in front of the child. Following implementing the first task (picture naming), the child was provided appropriate behavioral and verbal feedback. After a short rest, the second task (picture description) was completed. Executing the tasks took about 60 minutes, depending on the cooperation and tolerance of the children, and 15 minutes of rest time was between the two tasks. If signs of fatigue were observed on the child's face, the test was stopped and performed in a different session on the same day.

The participants' voices were recorded while performing the tasks of picture naming and picture describing. Then the broad phonetic transcription and five phonological indices of PMLU, PWP, PWC, PCC, and PVC were calculated. A single trained speech and language pathologist (SLP) conducted the tests and transcribed and analyzed the recorded samples. Table 1 presents the methods of calculating the indices. To ensure the accuracy of transcriptions and analysis, 10% of the recorded samples, including 10 samples, were randomly selected, separately transcribed, and re-scored by the examiner and a second SLP, and the phonological indices were calculated.

The intraclass correlation coefficient was used to calculate the intra-rater and inter-rater reliability. A coefficient >70% was considered acceptable and >90% was considered very acceptable [30]. In this study, the intra-rater and inter-rater reliability were >90%. Therefore, the reliability coefficients were acceptable.

Data analysis

SPSS software, version 22 was used for data analysis. Descriptive statistics were used to obtain the Mean±SD median, minimum, and maximum values. Regarding the non-normal distribution of the data specified by the Kolmogorov-Smirnov test, the Kruskal-Wallis test was used to compare the investigated phonological indices among the studied groups. The Wilcoxon test was used to compare these indices between the two tasks, including picture naming and description. Since the difference between the groups was significant, linear regression was used to control for confounding variables, such as age and sex.

Table 1. Method of calculating indices

Indices	Brief Definition	Calculation Method
PMLU	A phonological measurement method to assess the phonological complexity of words in speech.	Each produced consonant and vowel receives one point, and each correct consonant receives another.
PWP	An indirect index of word intelligibility that demonstrates the ratio of a child's correct production to the standard production.	The PMLU produced by the child divided by the PMLU produced by an adult is correct.
PWC	A simple measure to evaluate the overall accuracy of children's productions compared to the adult's production.	The number of correct words produced is divided by the total number of sample words.
PCC	To express the percentage of intended consonant sounds in a conversational sample that were articulated correctly.	The number of correct consonants is divided by the total consonants of the sample multiplied by a hundred.
PVC	Number of vowels produced correctly.	The number of correct vowels divided by the total number of the sample's vowels multiplied by a hundred.

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Abbreviations: PMLU: Phonological mean length of utterance; PWP: Phonological whole- word proximity; PWC: Proportion of whole-word correctness; PCC: Percentage of consonants correct; PVC: Percentage of vowel correct.

Results

This study included 100 children aged 3-6 with normal or impaired hearing. Table 2 presents the participants' demographic characteristics. Figure 1 shows the descriptive data related to the phonological indices, including PMLU, PWP, PWC, PCC, and PVC, in three groups and for both picture naming and picture description tasks.

According to Table 3, a comparison of the five phonological indices in the three studied groups using the Kruskal-Wallis test showed significant differences in the mean scores among the three groups of children with hearing aids, CI, and normal hearing ($P<0.05$). The group with normal hearing had better performance than children with hearing aids and CI, and children with CI had better performance than those with hearing aids.

Table 4 compares phonological indices between the two task of picture naming and description in each group. In the group of children who used hearing aids, a significant difference was observed between the phonological indices extracted from the two different tasks ($P<0.05$). These children scored better on the PWP and PWC indices in the picture-naming task and the PMLU, PCC, and PVC indices in the picture-description task. In the group of cochlear-implanted children, only the mean scores related to PMLU and PVC indices in the two tasks were significantly different ($P<0.05$), and they had better performance in both indices in the picture description task. In the group of children with normal hearing, the mean PMLU and PWC scores significantly differed between the two tasks ($P<0.05$). PMLU was higher in the picture description task, and the PWC index had higher scores in the picture-naming task.

A linear regression test was used to eliminate the effects of confounding variables, including sex and age (Table 5). The results showed that, considering the confounding variables, this model could predict more than 68% of all variables, except for the PVC index, which was approximately 20%.

Discussion

This study compared the PMLU, PWP, PWC, PCC, and PVC indices among three groups of children: Those with CI, those with hearing aids, and those with normal hearing. The comparison was conducted across two tasks: Picture naming and description. The results showed that children with normal hearing outperformed the other two groups significantly ($P<0.001$) across all indicators in both tasks. Additionally, cochlear-implanted children exhibited better performance than those with hearing aids. Children with hearing aids demonstrated a significant difference in all phonological indices in the picture naming and description tasks. A significant difference was observed only in the PMLU and PVC indices in the cochlear implantation group. In contrast, differences were noted in the PMLU and PWC indices in the normal hearing group.

As mentioned, the results showed that children with hearing impairment performed worse on all phonological indices compared to their normal peers. These results were consistent with those of Schauwers et al. who found that children with normal hearing exhibited superior performance in whole-word indices compared to cochlear-implanted children [26].

The current study's results are also consistent with the results of Baudnock et al. who demonstrated that children with CI and hearing aids tended to make more phonological errors and employ more phonological processes in their speech than children with normal hearing [31]. Additionally, Zanichelli revealed that children with normal hearing performed better in the PCC index than their counterparts with hearing aids [25]. The increased occurrence of consonant errors in hearing-impaired children with hearing aids and CI compared to those with normal hearing can be attributed to auditory sense deprivation, as children rely on auditory experiences to produce correct consonants [32]. Hearing loss can affect the connectivity of certain parts of the central auditory system and interfere with the development of the central

Table 2. Demographic characteristics

Sex Group	No. (%)		Total				Sig.
	Girl	Boy	No. (%)	Mean Age (m)	Min Age	Max Age	
Hearing loss with hearing aids	9(36)	16(64)	25(25)	57.68	36	72	
CI hearing loss	10(40)	15(60)	25(25)	63.64	38	72	0.121
Normal hearing	19(38)	31(62)	50(50)	60.26	36	72	

Table 3. Comparison of phonological indices between children with CI and hearing aids and children with normal hearing

Task Type	Indices	Group	Mean Rank	Sig.
Picture naming task	PMLU	HA	20.04	0.001
		CI	32.46	
		NH	74.75	
	PWP	HA	19.92	0.001
		CI	32.54	
		NH	74.77	
	PWC	HA	20.38	0.001
		CI	30.92	
		NH	75.35	
	PCC	HA	21.02	0.001
		CI	32.16	
		NH	74.41	
	PVC	HA	27.34	0.001
		CI	39.66	
		NH	67.5	
Picture description task	PMLU	HA	19.72	0.001
		CI	32.14	
		NH	75.07	
	PWP	HA	19.78	0.001
		CI	32.1	
		NH	75.06	
	PWC	HA	20.8	0.001
		CI	31.08	
		NH	75.06	
	PCC	HA	22.88	0.001
		CI	30.14	
		NH	74.49	
	PVC	HA	31.56	0.001
		CI	39.94	
		NH	65.25	

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Abbreviations: PMLU: Phonological mean length of utterance; PWP: Phonological whole- word proximity; PWC: Proportion of whole-word correctness; PCC: Percentage of consonants correct; PVC: Percentage of vowel correct; HA: Hearing aids; CI: Cochlear implants; NH: Normal hearing.

Table 4. Comparison of phonological indicators between the two tasks of naming the picture and describing the picture in all three studied groups

Groups	Indices	Mean Rank	Sig.
Hearing loss with hearing aids	PMLU (N) -PMLU (D)	13	0.001
	PWP (N)-PWP (D)	6.8	0.013
	PWC (N)-PWC (D)	7.6	0.012
	PCC (N)-PCC (D)	12.97	0.006
	PVC (N)-PVC (D)	10.3	0.026
CI hearing loss	PMLU (N)-PMLU (D)	13	0.001
	PWP (N)-PWP (D)	10	0.388
	PWC (N)-PWC (D)	11.79	0.153
	PCC (N)-PCC (D)	13.46	0.483
	PVC (N)-PVC (D)	5.31	0.017
Normal hearing	PMLU (N)-PMLU (D)	25.5	0.001
	PWP (N)-PWP (D)	4.67	0.156
	PWC (N)-PWC (D)	5.5	0.001
	PCC (N)-PCC (D)	10.56	0.375
	PVC (N)-PVC (D)	0	0.317

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Abbreviations: PMLU: Phonological mean length of utterance; PWP: Phonological whole- word proximity; PWC: Proportion of whole-word correctness; PCC: Percentage of consonants correct; PVC: Percentage of vowel correct; N: Phonological indices in the picture naming task; D: Phonological indices in the picture description task.

Note: Wilcoxon test, significance level<0.05.

auditory system, which plays a vital role in cognitive and language processing, especially phonological development. Therefore, the absence of hearing influences cognitive development. Studies have emphasized that early exposure to sound is vital for the typical development of cognitive abilities, including working memory associated with phonological development [31].

However, contrary to the results of the present study, Faes et al. found no significant difference in the phonological whole-word indices between the two groups of CI and normal-hearing children. This longitudinal study found a significant difference in the phonological whole word indices at the beginning of cochlear implantation. However, it disappeared and was eventually compensated for older ages. The results of their research are consistent with the conclusion that an increase in syllable length affects the phonological whole-word performance of children, and this is more effective in cochlear-implanted children [14].

Low and So showed a difference in the PCC index between the two groups of children with hearing aids and CI [32]. These researchers believed that CI are more effective than hearing aids in improving the phonological skills of hearing-impaired children, which is confirmed by the current research and other studies [33].

As mentioned above, this study's PCC and PVC indices differed significantly among the three groups. The group with normal hearing had better performance than the other two groups, and the mean scores of the CI group were significantly higher than those of children with hearing aids. These results were consistent with Sadat Seyedi et al.'s regarding the difference between children with normal hearing in the PCC index and the two groups of hearing-impaired children. However, the results did not match the difference between children with CI and hearing aids. Despite our results, the PVC index was almost the same in the three groups in the study by

Table 5. Examining the effect of confounding variables using linear regression

Task Type	Independent Variables	Dependent Variables	B	Std Error	Beta	t	Sig.	R Square	Adjusted R Square
Picture naming task	PMLU	Group	1.36	0.09	0.80	15.14	0.001	0.72	0.71
		Age	0.02	0	0.20	3.82	0.001		
		Sex	0.27	0.15	0.09	1.76	0.08		
	PWP	Group	0.17	0.01	0.81	15.39	0.001	0.73	0.72
		Age	0	0	0.20	3.85	0.001		
		Sex	0.03	0.01	0.09	1.80	0.07		
	PWC	Group	0.46	0.02	0.89	20.48	0.001	0.81	0.81
		Age	0	0	0.04	1.01	0.31		
		Sex	0.05	0.03	0.06	1.37	0.17		
	PCC	Group	0.25	0.01	0.77	13.48	0.001	0.68	0.67
		Age	0	0	0.22	3.86	0.001		
		Sex	0.05	0.03	0.10	1.85	0.06		
	PVC	Group	0.02	0	0.46	5.25	0.001	0.24	0.22
		Age	0	0	0.10	1.15	0.25		
		Sex	-0.01	0	-0.12	-1.41	0.16		
Picture description task	PMLU	Group	1.57	0.09	0.83	17.05	0.001	0.77	0.67
		Age	0.02	0	0.19	3.96	0.001		
		Sex	0.27	0.15	0.08	1.76	0.08		
	PWP	Group	0.17	0.01	0.83	17.10	0.001	0.77	0.76
		Age	0	0	0.19	4.04	0.001		
		Sex	0.03	0.01	0.09	1.85	0.06		
	PWC	Group	0.46	0.02	0.88	19.02	0.001	0.79	0.76
		Age	0	0	0.08	1.78	0.07		
		Sex	0.05	0.04	0.05	1.25	0.21		
	PCC	Group	0.22	0.01	0.73	11.71	0.001	0.62	0.61
		Age	0	0	0.22	3.54	0.001		
		Sex	0.03	0.03	0.07	1.17	0.24		
	PVC	Group	0.02	0	0.43	4.83	0.001	0.22	0.20
		Age	0	0	0.12	1.38	0.16		
		Sex	-0.01	0	-0.13	-1.47	0.14		

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Abbreviations: PMLU: Phonological mean length of utterance; PWP: Phonological whole- word proximity; PWC: Proportion of whole-word correctness; PCC: Percentage of consonants correct; PVC: Percentage of vowel correct.

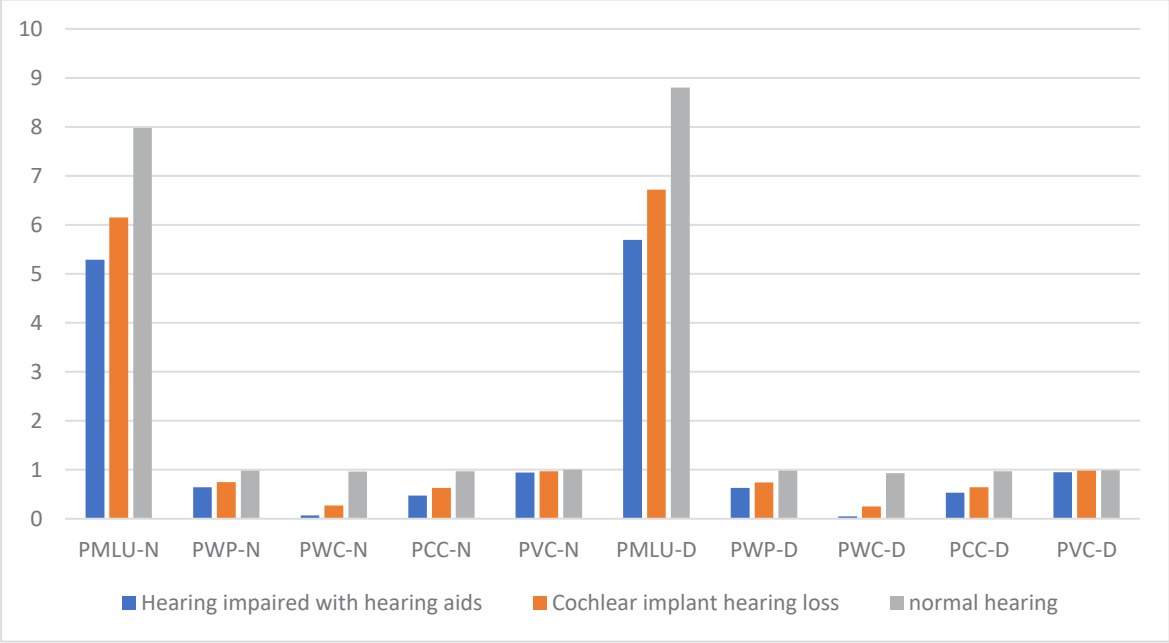

Figure 1. Descriptive data of phonological indices in three groups and in the two tasks of naming the picture and describing the picture

N: Phonological indices in the picture naming task; D: Phonological indices in the picture description task.

Sadat Seyedi et al. [34]. These differences may be due to the different characteristics of the participants in the two studies. The participants in Seyedi's study were only 6-year-old children, while in the present study, the age range of the children was 3-6 years [34].

In Yi 's research, the average PCC index was 75% in children with CI and 74% in children with hearing aids, which differs from our results. This difference may be due to the different age groups and input criteria, including the degree of hearing loss [23].

Co-articulation is influenced by the context of a word and adjacent sounds [35]. The speech units are not separate from each other in the word and the sentence, and in conversational speech, it is clear that the phonological properties of words affect the words before and after them [36, 37]. As a result, people do not perform similarly when evaluating picture naming and description.

In the present study, children with hearing aids revealed a significant difference in all phonological indices in picture naming and description. Since no similar research findings were observed, the children's better performance in PMLU, PCC, and PVC indices in picture description compared to picture naming might be related to the grammatical features of the Persian language. Using the grammatical features of the Persian language changes the syllabic context of words, and the increase or decrease of syllable length and context changes directly affect these indices.

Faes et al. have shown that children with CI differ in phonemic accuracy from children with normal hearing, not by their hearing status alone, but by the interaction between their hearing status and the complexity and length of target words. The production of longer and more complex words differentiates the two groups, not the production of short and simple words [14]. Faes et al. stated that in children with normal hearing or CI, it is unclear how the context of speech sampling affects phonemic accuracy, and that further research is needed on this [22].

The relationship between grammatical and phonological features has been the research subject, with various studies conducted in this field. Some linguists believe that the relationship between a language's grammatical and phonological areas is related to each language's specific characteristics. All these cases have in common that the addition or subtraction of suffixes and grammatical prefixes affects the type and texture of words, and the type of effect changes depending on the texture and class of the word [38, 39]. However, the relationship between

grammatical features and phonological indicators must be further investigated in children's speech. In addition, these results are consistent with the research of Willis, Faes et al. who showed that an increase in syllable length decreases production accuracy [14, 23, 40]. For example, when the child uses the object /ra/ as an abbreviation in the sentence /pesār chātro bārdāʃt/, the syllabic texture of /chātr/ (umbrella) changes from monosyllabic to bisyllabic, and the word with a consonant cluster becomes a word without a cluster. The CVCC texture changes to two CVC-CV syllables.

Also, the results showed a significant relationship between age and hearing ability with all phonological indices except PVC. Consistent with the study's results, Ingram [16] and Taelman et al. [24] showed that the amount of PMLU increases with age. Zanichelli found that the PCC index was greater in children with normal hearing than those with hearing loss [25]. Schauwers et al. concluded that the performance of Dutch children with CI is weaker than that of their peers with normal hearing in phonological indices [26]. Also, Baudonck et al. investigated phonological processes and determined that children with hearing aids have more phonological errors than those with CI [31]. This study had limitations, including the lack of access to the exact age of hearing loss and the extended sampling time due to the spread of the coronavirus pandemic and the closure of the centers during the peak times of the coronavirus. Based on the results and limitations of this study, the following suggestions are made for future research:

1) The role of morphological-syntactic features in the phonological indicators of the whole word should be investigated; 2) Despite the research team's great efforts to control confounding factors, it is suggested that factors, such as the exact time of hearing loss diagnosis, the use of a prosthesis, and the start and number of sessions and type of treatments should be controlled. 3) To determine the range of PMLU, PWP, and PWC indices in normal Persian-speaking children in longitudinal studies. 4) To investigate and research whole word phonological indicators in other children with speech sound disorders and bilingual children.

Conclusion

This study showed a significant difference in the three groups studied, the phonological indices of the whole word PMLU, PWP, PWC, PCC, and PVC indices. Children with normal hearing had better performance than cochlear-implanted and hearing-impaired children, and cochlear-implanted children also had better performance than children with hearing aids. The results of the present study showed that the phonological characteristics of hearing-impaired children are deficient due to the lack of a sense of hearing and require a detailed speech therapy program. Using a CI has a greater effect on improving a hearing-impaired child's performance in phonology. Also, whole word indices, such as PMLU, which relate to word complexity and length, better show phonological features in the two tasks of picture naming and picture description. Therefore, in the phonological assessment and treatment of hearing-impaired children, in addition to focusing on different parts of the word (consonants and vowels), we should not only focus on the different parts of the word (consonants and vowels), but also on the phonetic indicators of the whole word and the selection of the target vocabulary.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Ethics Committee of Mashhad University of Medical Sciences, Mashhad, Iran (Code: IR.MUMS.REC.1399.615). The research project was explained to the parents of children who met the inclusion criteria, and after signing the consent form, their child entered the study.

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Authors' contributions

Conceptualization and study design: Fatemeh Haresabadi; Data collection: Haniyeh Jafarzadeh, Fatemeh Haresabadi, and Majid Haddadi Avval; Data analysis: Zahra Abbasi Shaye; Writing the original draft: Toktam Maleki Shahmahmood, Haniyeh Jafarzadeh, and Fatemeh Haresabadi; Review and editing: Zahra Ghayoumi-Anaraki and Toktam Maleki Shahmahmood; Final approval: All authors.

Conflict of interest

The authors declared no conflict of interest.

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