Research Article

Phonological Processing and Word and Non-Word Reading Ability among Farsi-Speaking Children with Cochlear Implants, Hearing Aids and Normal Hearing

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Highlights

- Auditory input plays an important role in acquiring phonological processing skills
- Phonological processing skills in children with HL are weaker than NH
- Phonemic awareness was the most important predictor for reading abilities

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ABSTRACT

Background and Aim: Individuals who suffer Hearing Loss (HL) from inefficient auditory input will experience difficulty in phonological processing and reading. This study aimed to investigate the phonological processing and word and non-word reading abilities of Farsi-speaking children with Cochlear Implants (CIs), Hearing Aids (HAs) and Normal Hearing (NH).

Methods: Sixty-three children with severe to profound HL and NH who were in the first grade participated. Phonological Awareness (PA) and Phonological Working Memory (PWM) tests were used to assess phonological processing. Word and non-word reading abilities were assessed through reading and dyslexia tests reading abilities, phonological processing as well as the correlation between them were compared among three groups.

Results: The PA, PWM and reading abilities of NH children were significantly different from children with HL ($p<0.01$). Correlations between words and non-words reading ability and some phonological processing tasks were observed in each of the three groups. Phonemic awareness for all three groups and intra-syllabic awareness for children with HA and NH were the most important predictors for word and non-word reading abilities.

Conclusion: Hearing impairment had a critical effect on phonological processing as an important factor in word and non-word reading.

Keywords: Cochlear implant; hearing aid; reading; phonological processing; Farsi-speaking children

Introduction

Word and non-word reading abilities are related to phonological processing ability [1]. Phonological processing is the capacity to encode and decode speech as well as to store, maintain, manipulate and retrieve phonological information. Auditory-perceptual representations are abstract and stored in the mental lexicon [2], thorough Working Memory (WM) [3]. Phonological processing skills involved in word and non-word reading abilities require the development of phonological representations [4]. It is generally examined through Phonological Awareness (PA), Phonological Working Memory (PWM) and phonological retrieval [5].

PA is an extensive ability to detect and manipulate spoken language units such as words, syllables, onset and rime [3]. Children begin to develop PA through awareness of larger speech units (words, syllables), which produces awareness of smaller segments (phoneme, onset-rime) [6].

WM is the function of temporarily storing and processing information. Phonological loops as a component of WM [7] is responsible for short-term storage and rehearsal of verbal information. This component can store acoustic traces of speech that are prone to decay (two seconds) [8]. It also involved in reading tasks [7].

The PWM is usually measured by Non-Word Repetition (NWR), Forward Digit Span (FDS) and Backward Digit Span (BDS) tasks [9]. The FDS and BDS tasks are easier than the NWR task because the child will be familiar with the phonetic strings in these two tasks [10].

HL will prevent children from attaining proper access to a language-rich environment during early ages of language acquisition [11]. Such children will show low-level language skills typified by defects in speech production and perception, less vocabulary knowledge and defects in morphological-syntactic structures [12, 13].

Hearing Aids (HAs) and Cochlear Implants (CIs) do not provide normative access to auditory signals. This poor-quality phonological representation will cause problems with their PA and word reading skills [2, 14].

There is a strong and positive correlation between PA and reading abilities for children with CIs [15]. It has been showed that PA is an important predictor of reading ability in school-age children with CIs and HAs [2, 16].

The phonological system is stronger for children with CIs compared to children with HL without CIs but weaker than for NH children [3, 5, 17]. Children with CIs and HAs compared to NH children also have been found to experience WM difficulties, especially on FDS, BDS and NWR tasks [3, 4, 10, 18].

Children with CIs only were able to produce 5% of real non-words correctly [19]. They scored lower on NWR and digit span tasks than did their hearing peers [10]. Impairment of phonological processing in such children led to impaired language development and reading ability [20].

Given the importance of phonological processing in reading development, and the scant knowledge about the correlation between reading and phonological processing of Farsi-speaking children with CIs and those with HAs motivated us to examine the correlation between their reading abilities and phonological processing. We also compared these abilities with those of Farsi-speaking NH children.

Methods

Participants

After receiving written consent from the parents, children with CIs, HAs and NH (21 children in each group), who were studying at their first year of elementary school participated. All of participants were native speakers of Farsi and had normal intelligence quotients. They did not reveal any structural or motor speech problems. They had no history of failure in the first grade.

The participants with bilateral CIs aged 7 years to 7.11 years (7 years+11 months). They had congenital severe-to-profound bilateral Sensorineural Hearing

Loss (SNHL) and had been fitted with nucleus freedom system CIs with 22 channels. The children had at least three years of experience using the CI (mean hearing age=61 months; standard deviation (SD=7). They studied in schools alongside NH students and could easily communicate with their classmates.

The participants with bilateral HAs were matched with the children with CIs according to the described features and gender. These children also had severe-to-profound congenital bilateral SNHL and had used conventional amplifier hearing aids for at least three years (mean auditory experience=72 mo.; SD=6). These children aged 8 to 8.11 years. They studied in special schools for children with HL. The children regularly passed the first grade after two years of study in these schools. This means that these children with HAs were older than the other two groups. Their language difficulties were only the result of HL. The minimum and maximum ages for receiving a CI and a HA were 12 and 36 months, respectively (mean=26 months; SD=7). Considering conversational speech samples, the mean length of utterance scores for children with CI and HA were above 4. It was calculated based on words. They had the ability to verbally communicate with the examiner and understood the instructions for the tasks. They received oral training in the classroom and had never been instructed in sign language. The age and gender of the NH participants were matched to the children with CIs. They had no significant developmental disabilities according to medical reports.

Materials

The reading and dyslexia tests [21], the PA test [22] and the PWM tasks of the NWR [23], FDS and BDS [24] were performed. The responses of the subjects were registered during the test and the subjects' responses were recorded by a voice recorder so that they could be corrected and any missed responses could be noted.

Procedure

Reading ability was evaluated using the reading and dyslexia subtests for non-word reading and word reading. For the non-word reading task, the participants read a list of 40 non-words. For the word reading task, 120 words from three lists comprising either high, moderate or low frequencies were presented [21].

Phonological processing was assessed using the PA test [22] and NWR test [23], FDS and BDS as two subtests of WISC-R [24]. Phonemic awareness (seventy questions), syllabic awareness (ten questions) and intra-syllabic awareness (twenty questions) are three subtests of PA. The total score for phonological awareness was 100 [22]. In the NWR task, the children were asked to repeat correctly 25 words that had no meaning. The total possible score for each child was 25 [23]. In FDS and BDS tasks, the subject is asked to repeat seven strings of numbers. Each string contained 3 to 9 numbers for the FDS and 2 to 8 numbers for the BDS. The maximum score for each task was 14. The FDS task was performed first, then the BDS task was performed.

The ANOVA tests and Tukey's post-hoc test were done to compare the means of the three groups of children. The NWR did not have normal distributions; therefore, the Kruskal-Wallis and Mann-Whitney U non-parametric tests were performed. The Pearson's and Spearman's correlation coefficient were calculated to detect the relationship between phonological processing and the reading tasks. Coefficients of between 0 and 0.39 considered as a weak correlation, between 0.40 and 0.69 indicated a moderate correlation and between 0.70 and 1 indicated a strong correlation [25].

Multiple regression analysis was used to determine which measured variable predicted the outcome of reading in children with hearing loss.

Results

The demographic characteristics of age, sex, age at which a CI or HA was received and the duration of use are listed in Table 1.

There were a significant difference between groups for word reading ($F_{(2,60)}$=7.92; p=0.001), non-word reading ($F_{(2,60)}$=10.31; p<0.001), FDS ($F_{(2,60)}$=21.72; p=0.0001), BDS ($F_{(2,60)}$=8.35; p=0.001), syllabic awareness ($F_{(2,60)}$=7.92; p<0.0001).

There were significant differences between the three groups for the NWR (x^2=79.39; df=2; p<0.001). It was indicated that NH children scored significantly higher for all variables than children with CIs and HAs (p<0.05). There was no significant difference between children with CIs and HAs (p>0.05). The results of the

Table 1. Participant demographic characteristics

	Age (months) Mean±SD	Gender		Hearing age (months) Mean±SD(min-max)	Duration of using hearing aids Mean±SD(min-max)
		Female, n(%)	Male, n(%)		
CIs	88±3	10(47.62)	11(52.38)	26±7(12–36)	61±7(48–71)
HAs	98±2	10(47.62)	11(52.38)	26±7(12–36)	72±6(64–88)
NH	88±3	10(47.62)	11(52.38)		

CI; cochlear implant, HA; hearing aids, NH; normal hearing

Table 2. Mean and standard deviation for reading, phonological working memory and phonological awareness

Subtest	Mean(SD)			NH *vs* CIs (p) *	NH *vs* HAs (p)*	CIs *vs* HAs (p)*
	CIs (n=21)	HAs (n=21)	NH (n=21)			
Word reading	62.23(32.23)	69.04(30.34)	98.09(22.64)	0.002	0.005	0.940
Non-word reading	22.00(10.57)	20.47(11.71)	33.38(7.39)	0.002	<0.001	0.870
FDS	5.19(1.16)	5.14(1.23)	7.42(1.43)	<0.001	<0.001	0.992
BDS	3.52(2.15)	2.85(2.12)	5.23(1.48)	0.016	0.001	0.512
NWR	15.33(5.70)	11.90(6.31)	24.57(0.81)	<0.001	<0.001	0.070
Syllabic awareness	8.52(1.80)	7.71(2.45)	10.00(0.00)	0.023	<0.001	0.300
Intra syllabic awareness	12.04(4.29)	12.66(4.58)	17.61(1.88)	0.001	0.001	0.850
Phonemic awareness	29.00(16.28)	26.66(12.24)	58.38(8.37)	0.001	0.001	0.820

CI; cochlear implant, HA; hearing aids, NH; normal hearing, FDS; forward digit span, BDS; backward digit span, NWR; non-word repetition
* Pairwise results of the Tukey and Mann-Whitney U tests

Tukey and Mann-Whitney U tests are listed in Table 2.

Table 3 reveals the correlations between the total scores for the different PA subtests and the word and non-word reading abilities.

Stepwise linear regression analysis was performed for variables with normal distributions (total scores for phonemic awareness, intra-syllabic awareness, FDS, BDS). The most significant predictor of word reading ability for children with CIs was the total score for phonemic awareness (R^2=0.63; β=0.63; t=3.54; p=0.002). The total scores for intra-syllabic awareness (R^2=0.88; β=0.49; t=2.80; p=0.01) and phonemic awareness (R^2=0.88; β=0.45; t=2.57 p=0.01) were the most significant predicators for children with HAs. For NH children, the total scores for phonemic awareness (R^2=0.74; β=0.45; t=2.59; p=0.01) and intra-syllabic awareness (R^2=0.74; β=0.42; t=2.41; p=0.02) were the best predictors. The most significant predictor for non-word reading ability in children with CIs was the total score for phonemic awareness (R^2=0.65; β=0.65; t=3.77; p=0.01). The total score for intra-syllabic awareness (R^2=0.70; β=70; t=4.35; p<0.001) was the most significant predictor for children with HAs and NH children (R^2=0.47; β=0.47; t=0.37; p=0.02).

Discussion

This study compared the word and non-word reading abilities and phonological processing skills of children with CIs, HAs and NH. This study also investigated the correlation between phonological processing and word and non-word reading abilities within each group.

Table 3. The correlation between the phonological working memory, phonological awareness and word and non-word reading abilities

		CIs		HAs		NH	
		Word reading	Non-word reading	Word reading	Non-word reading	Word reading	Non-word reading
Working memory	FDS r(p)	0.45(0.037)*	0.49(0.024)*	0.27(0.222)	017(0.440)	0.49(0.022)*	0.46(0.036)*
	BDS r(p)	0.39(0.078)	0.46(0.034)*	0.48(0.025)*	0.60(0.004)**	–0.03(0.895)	–0.04(0.846)
	NWR r(p)	0.21(0.343)	0.17(0.446)	0.24(0.288)	0.42(0.058)	0.52(0.015)*	0.21(0.356)
Phonological awareness	Syllabic awareness r(p)	0.43(0.052)	0.44(0.042)*	0.61(0.003)**	0.69(0.001)**	a	a
	Intra-syllabic awareness r(p)	0.41(0.020)*	0.42(0.020)*	0.84(0.000)**	0.70(0.000)**	0.62(0.001)**	0.47(0.010)*
	Phonemic awareness r(p)	0.63(0.001)**	0.65(0.001)**	0.83(0.000)**	0.65(0.001)**	0.64(0.001)**	0.36(0.050)*

CI; cochlear implant, HA; hearing aids, NH; normal hearing, FDS; forward digit span, BDS; backward digit span, NWR; non-word repetition, a; correlation cannot be calculated because one of the variables is constant.
* $p<0.05$, ** $p<0.01$

The children with HL showed reduced performance in PA tasks in comparison with NH children. This result is consistent with the findings by Lee et al. [3], and Spencer and Tomblin [5]. Development of PA is influenced by receptive and expressive language skills, vocabulary, speech production and literacy instruction. These skills are strongly related to hearing experience [2, 16].

For children with HL, the quality of the representation of the phoneme is lower than for their NH peers [3]. It appears that the lack of a significant difference between the children with HL was that those with HAs were one year older than the children with CIs, although the age of access to hearing aid equipment was almost the same for both groups. Teaching sound-based reading strategies as well as being exposed to letters and reading for a longer period of time can strengthen PA skills [26].

Similar to other studies [3, 4, 5, 10, 18], the performance of both groups of children with HA and CI users on PWM tasks was lower than for NH children. Auditory experience in the early stage of development has an important effect on the growth of the human memory system [10]. This means that speech comprehension difficulties following HL will decrease the cognitive resources required to maintain and process phonological representations [2].

It has been reported that working memory develops as children age [10]. Although children with HAs were older than the children with CIs in the present study, in this no difference between the groups was observed.

The reading ability in children with HL in both groups was significantly lower than for their NH peers. It has been found that the development of language and speech skills, especially vocabulary and the quality of phonological representations, is higher for NH children than for children with HL [2, 4, 15].

Despite the differences in educational environment, teaching materials and methods, the performances on the reading tasks were the same for CI and HA users. These results of correlation between syllabic awareness and non-word reading; and between syllabic awareness and word reading in children with CIs are in accordance with those of Furlonger et al. [27]. Their devices are not able to cover information at the phoneme level. The current study similar to Badin indicated that syllabic awareness is not a predictor for word and non-word reading abilities in NH children [28].

Our study similar to other studies [28] showed that, in the initial steps of formal literacy training, intra-syllabic awareness has a significant effect on the development of reading ability. It is possible that, in the initial steps of reading, they turn their attention to letters that are similar at the beginning or at the end of spoken words.

Confirming the results of previous studies [27, 28], this study also revealed that phonemic awareness had a positive correlation with word and non-word reading abilities in all groups. Thus, it is possible that Farsi-speaking children rely on phoneme-letter correspondence more while initially learning to read. Therefore, phonemic awareness can be considered as depiction of the adequacy of phonological representation in NH children and children with HL [14].

The correlation between both word and non-word reading and FDS in the CIs and the NH children are in line other studies that have found a correlation between WM and reading ability [5, 17]. The findings show that the FDS task as well as word and non-word reading require access to phonological information and representations. PWM plays a role in reading performance by storing sound units during phonological processing. It also contributes to phoneme-letter correspondence [29].

In our study, the performances of children with HA and children with CIs was not significantly different in all phonological processing tasks. It was not clear why their scores on the correlation between FDS and reading abilities were different. It is likely that the children with HAs used different phonological processing for the FDS, word reading and non-word reading tasks.

No significant correlation existed between BDS and word and non-word reading for NH children. The BDS task is a complex working memory task that engages the central executive. This task requires active controlled attention and conscious allocation of cognitive processing resources [30]. Children with NH require fewer controlled skills for word recognition than children with HL in the reading task. Savage et al. [7] showed this result as well. The significant correlation between BDS and non-word reading in children with HL suggests that non-word reading requires more attention and that these children use extensive cognitive resources when decoding non-words. These results also are in accordance with those of von Mentzer et al. [18].

The result of correlation between NWR and word reading in NH children is in line with those of previous studies that showed phonological processing skills measured by NWR are related to reading ability in NH children [31]. It appears that the quality of phonological representation in tasks such as NWR is an important factor in both decoding ability and phonological processing skill [4, 14]. There was no correlation between NWR and non-word reading in NH children. This finding is contrary to the findings of von Mentzer et al. [18] and Hansen and Bowey [1]. This difference could be related to the sample size of studies.

Lack of significant relationship between NWR with word and non-words reading for both groups of children with CIs and HAs are consistent with the results by von Mentzer et al. [18]. The lack of a significant relationship confirmed that the PWM involved in the NWR task may be less related to language and literacy in children with HL [31]. This result is inconsistent with the findings of Dillon and Pisoni [4].

The results of regression analysis suggest that learning to read requires proper phoneme-letter correspondence in alphabetic systems such as the Farsi language. The present study, as well as other studies [14, 28], have shown that smaller phonological units have better predictive power for reading abilities.

We were not able to match the children for language skill, school settings and age. There also was no information available about pre-school literacy training for these children. In addition, it is suggested that future studies conduct a normal speech comprehension test as an inclusion criterion.

Conclusion

The skills of children with Hearing Loss (HL) on phonological awareness, phonological working memory and word and non-word reading tasks were weaker than for normal hearing children. Intra-syllabic awareness and phonemic awareness are the main predictors of reading ability in children with HL.

Ethical Considerations

Compliance with ethical guidelines

The current investigation received approval from the Ethics Committee of Tehran University of Medical Sciences in Iran (IR.TUMS.VCR.REC.1395.1039).

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Authors' contributions

EM: Writing-original draft, interpretation of the results; AH: Study design, acquisition of data, interpretation of the results; ZS: Supervisor, study design, statistical analysis, interpretation of the results, review and editing.

Conflict of interest

No potential conflict of interest relevant to this article was reported.

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