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Research Article

Speech-in-Noise Recognition in School-Aged Children with Hearing Loss: Evidence of a Critical Condition

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Abstract

Previous research findings demonstrated that cochlear implants (CIs) users have essential challenges with speech recognition in the presence of background noise. Therefore, this study aimed to determine speech-in-noise (SiN) perception in Persian school-aged children with CIs/hearing aids (HAs) compared to their peers with normal hearing (NH). The research was administered as a cross-sectional study. Speech-in-noise performance in thirty-three school-aged children with hearing loss (19 unilateral CIs users and 14 bilateral HAs users) was compared to twenty school-aged children with normal hearing by using the Persian Lexical Neighborhood Tests (PLNTs). To make sure that floor or ceiling effects would not affect the children's performance, the PLNTs were performed by the sound field at different levels of signal-to-noise ratio (SNR). The SiN performance on all four subscales of the PLNTs was significantly poorer in Persian school-aged CIs/HAs users than their peers with NH for all stepwise increases in the SNR ($P < 0.001$). The Persian school-aged CIs users experience a critical condition related to listening spectrally degraded speech in noisy environments such as home, school, and classroom due to SiN perception insufficiency.

INTRODUCTION

A critical condition faces school-aged children with hearing loss (HL) who risk academic learning problems due to deficiency of speech-in-noise (SiN) perception [1,2]. Previous research findings demonstrated that cochlear implants (CIs) users have significant challenges with speech recognition in the presence of background noise [3-9]. In noisy conditions, they experience significant listening and communication problems in various verbal interactions in everyday life [10,11]. Further, language ability is one of the determining factors of children's SiN perception [5,6,12,13]. Conversely, SiN perception problems can adversely affect spoken language development [6,14]. That is, the speech recognition of school-aged children with HL correlates with their spoken language performance [6,15,13]. School-aged children with HL may be exhausted in typical classroom environments due to the need to expend more effort listening than their peers with normal hearing (NH) [16].

Although the findings showed that the pediatric CIs recipients had poor performance in both speech perception in quiet [17-19] and in noise [20,21,1-2,13] compared to their peers with NH, as Zaltz et al., noted, fewer studies have been administered to assess SiN perception in prelingually deafened CI users than postlingually ones [9]. Accordingly, merely six examinations have been issued on SiN perception in Persian pediatric CIs users [22-27], and among them, three studies were focused explicitly on Persian preschool- and school-aged children with and without HL [24-27]. Their findings emphasized the children's poor performance on SiN perception.

According to a recent systematic review by Oryadi-Zanjani et al. [28], there are just two practical assessment tools to measure SiN perception in Persian children so far include the Persian Lexical Neighborhood Tests (PMLNTs and PDLNTs) [29] and the Persian version of the words-in-noise [30]. In their studies, Oryadi-Zanjani and Vahab explained the PLNTs and the PLNTs-preschool version (PLNTs-PV) as valid assessment toolkits to measure SiN perception in children with HL [24,26-27]. Hence, to design and execute experimental studies to find an efficient interventional approach for improving children's listening performance in background noise, it is necessary to perform more specific studies on the children's problems in listening under spectrally degraded conditions. Therefore, considering the SiN perception, this study aimed to determine SiN recognition in Persian school-aged children with HL compared to their peers with NH using the PLNTs. The assumption was the children using CIs or HAs performed significantly poorer than those with NH.

METHODS

The research was administered as a cross-sectional study. Informed consent was obtained from the parents of the children participating in the study, and the research protocol was approved by the Ethics Committee of Shiraz University of Medical Sciences, Shiraz, Iran (the approval number: IR.SUMS.REC.1396.S39). The aim was to assess SiN in Persian school-aged children with HL using the Persian Lexical Neighborhood Tests (PLNTs) [28,29] and to compare the children's SiN performance with their peers with NH.

Participants

Twenty Persian-speaking children with NH between the ages of 6 to 12 years (mean = 9.35) were recruited through convenient sampling from a primary school in Shiraz, Iran. The inclusion criteria included: age, Persian-speaking, normal hearing thresholds, typical communication, speech and language skills, average literacy, and moderate-to-high educational status. The participant's health status was verified by each child's school health case record and by interviewing teachers and parents. Accordingly, all of them had normal hearing thresholds.

Thirty-three 7-to-13-year-old children with severe to profound HL (mean = 9.12; 19 unilateral CIs users and 14 bilateral hearing aids (HAs) users) were recruited through consecutive sampling methods from primary schools in Shiraz, Iran. All participants met the following inclusion criteria: 1) spoken Persian as the primary language, 2) a bilateral symmetrical sensorineural congenital HL with pure tone average thresholds > 30 dB HL, 3) normal tympanometry bilaterally, 4) the age of hearing aid fitting under two years old, 5) the age of implantation under three years old, 6) using oral language as communication method pre- and post-implantation, 7) using HAs as a trial before cochlear implantation, 8) educated in Soroush Auditory Rehabilitation Center in Shiraz, Iran, before entering school, and 9) no additional handicapping conditions.

Assessment tools

Oryadi-Zanjani and Zamani et al. [29], developed a lexically controlled assessment toolkit (4 subscales) entitled the Persian Lexical Neighborhood Tests (PLNTs) based on the Neighborhood Activation Model to measure SWR in Persian-speaking children which includes: The Persian Monosyllabic Lexical Neighborhood Tests (PMLNT-easy [18 words] and PMLNT-hard [27 words]) and the Persian Disyllabic Lexical Neighborhood Test (PDLNT-easy [18 words] and PDLNT-hard [27 words]). The PLNTs were administered to 20 Persian-speaking 7-to-13-year-old children with NH. They concluded that the PLNTs are a practical language-independent toolkit to assess the SWR of Persian-speaking children under spectrally degraded conditions [29].

Procedure

We followed the instructions listed in the study of Oryadi-Zanjani and Zamani et al. [29], to examine the children. Accordingly, the experiments were administered on -2, 0, 2, 4, and 15 dB SNR to ensure that floor or ceiling effects would not affect the children's performance. All stimulus words were presented at each of these SNRs. All twenty participants with NH and thirteen with HL (CIs users = 3 and HAs users = 10) completed the examination. In other words, 20 participants (CIs users = 16 and HAs users = 4) could not hear the words in the noise. The means of the participants' scores were compared statistically through IBM SPSS version 23 software at the significance level 0.05.

RESULTS

The means and the standard deviations of the scores of school-aged children with HL and their peers with NH in the PLNTs based on the SNR levels are shown in Table 1.

Comparison of mean scores on PMLNT-easy

The mean scores on the PMLNT-easy in the SNR levels (-2 to 15 dB) were compared between the children with HL and those with NH by the Repeated Measures ANOVA. A significant difference was found between the two groups for all stepwise increases in the SNR ($P < 0.001$) (Figure 1).

Comparison of mean scores on PMLNT-hard

The mean scores on the PMLNT-hard in the SNR levels (-2 to 15 dB) were compared between the children with HL and those with NH by the Repeated Measures ANOVA. A significant difference was found between the two groups for all stepwise increases in the SNR ($P < 0.001$) (Figure 2).

Table 1: The scores of children with and without hearing loss in the PLNTs based on SNR levels

Subscales	Number	SNR (dB)	Children with HL	Children with NH
			Mean (SD)	Mean (SD)
PMLNT-easy	HI-test = 13 HI-retest = 9 NH= 20	-2	0.18 (0.11)	0.63 (0.08)
PMLNT-hard			0.15 (0.11)	0.46 (0.09)
PDLNT-easy			0.44 (0.17)	0.76 (0.08)
PDLNT-hard			0.29 (0.12)	0.69 (0.07)
PMLNT-easy		0	0.25 (0.17)	0.75 (0.09)
PMLNT-hard			0.17 (0.10)	0.52 (0.10)
PDLNT-easy			0.54 (0.17)	0.84 (0.05)
PDLNT-hard			0.35 (0.17)	0.76 (0.08)
PMLNT-easy		2	0.34 (0.25)	0.80 (0.09)
PMLNT-hard			0.21 (0.09)	0.65 (0.10)
PDLNT-easy			0.65 (0.15)	0.89 (0.04)
PDLNT-hard			0.50 (0.13)	0.80 (0.07)
PMLNT-easy		4	0.34 (0.16)	0.84 (0.06)
PMLNT-hard			0.29 (0.10)	0.69 (0.12)
PDLNT-easy			0.70 (0.11)	0.91 (0.04)
PDLNT-hard			0.54 (0.13)	0.84 (0.07)
PMLNT-easy	HI-test = 33 HI-retest = 9 NH = 20	15	0.70 (0.19)	1
PMLNT-hard			0.58 (0.15)	1
PDLNT-easy			0.85 (0.18)	1
PDLNT-hard			0.71 (0.10)	1

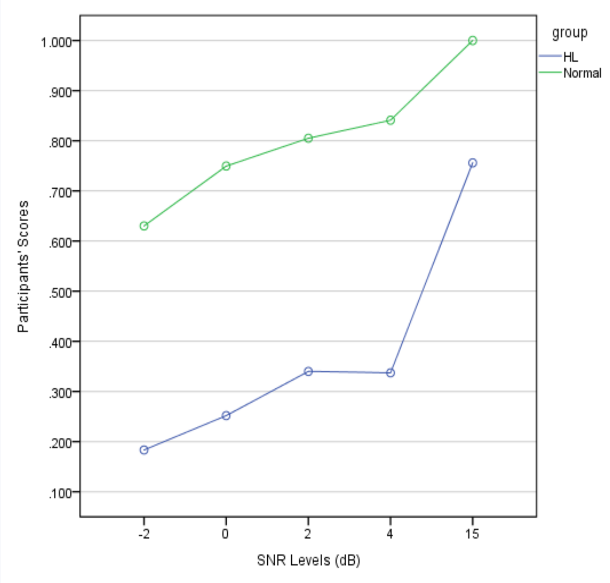

Figure 1 Comparison of the PMLNT-easy scores between children with and without hearing loss

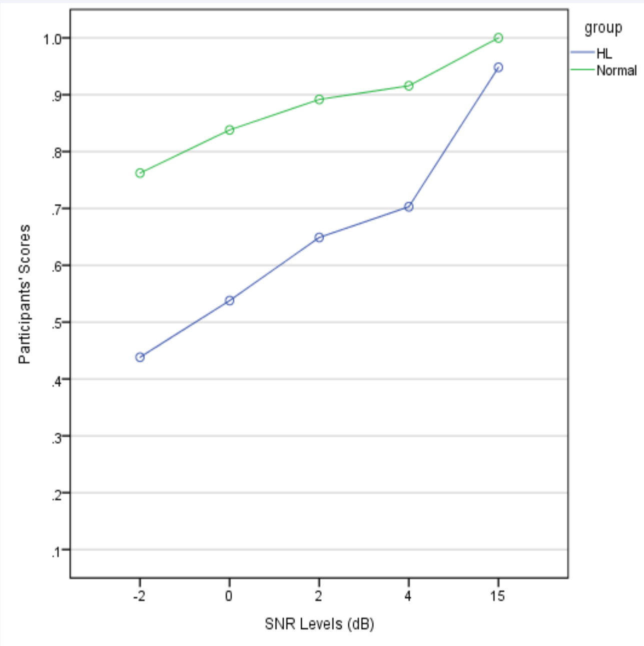

Figure 2 Comparison of the PMLNT-hard scores between children with and without hearing loss

Comparison of mean scores on PDLNT-easy

The mean scores on the PDLNT-easy in the SNR levels (-2 to 15 dB) were compared between the children with HL and those with NH by the Repeated Measures ANOVA. A significant difference was found between the two groups for all stepwise increases in the SNR ($P < 0.001$) (Figure 3).

Comparison of mean scores on PDLNT-hard

The mean scores on the PDLNT-hard in the SNR levels (-2 to 15 dB) were compared between the children with HL and those with NH by the Repeated Measures ANOVA. A significant difference was found between the two groups for all stepwise increases in the SNR ($P < 0.001$) (Figure 4).

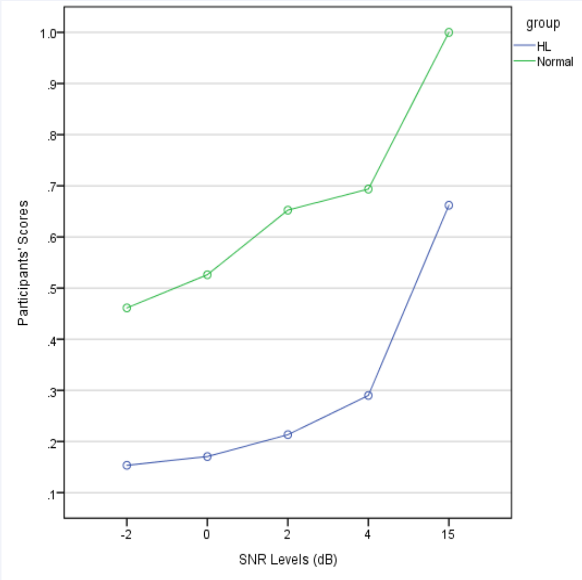

Figure 3 Comparison of the PDLNT-easy scores between children with and without hearing loss

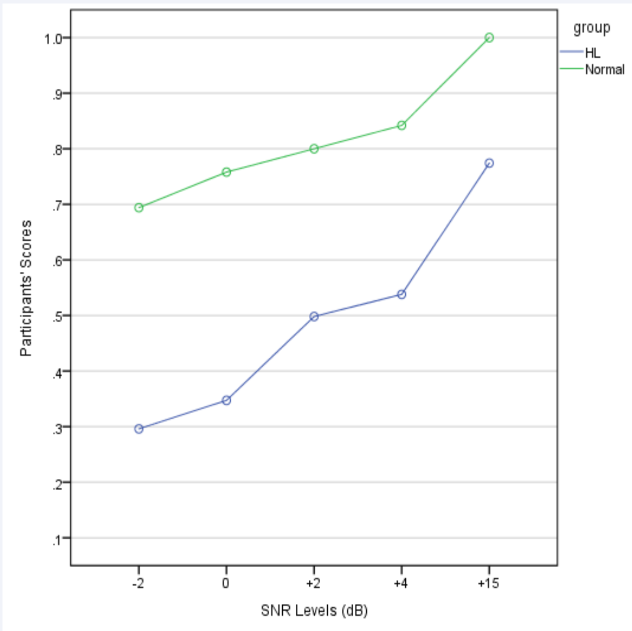

Figure 4 Comparison of the PDLNT-hard scores between children with and without hearing loss

Comparison of differences in the means of PLNTs scores

As shown in Table 2, the differences in the means of PLNTs scores in the SNR levels (-2 to 15 dB) were compared between the children with HL and those with NH by the Independent-Samples T-Test. The differences of the PLNTs' mean scores (D) were significantly different between the two groups, including D1 = the PMLNT-easy minus the PMLNT-hard (0 and 15 dB), D2 = the PDLNT-easy minus the PDLNT-hard (0, 4, and 15 dB), D3 = the PDLNT-easy minus the PMLNT-easy (-2, 0, 2, 4, and 15 dB), and D4 = the PDLNT-hard minus the PMLNT-hard (-2, 2, 4, and 15 dB). Except for D1 (0 dB) and D4 (-2 dB), the differences in the children with HL were higher than their peers with NH. There was also a constant trend in D3 in all SNR levels.

Table 2: Comparison of the differences of the PLNTs subscales between children with and without hearing loss

Differences	N	SNR levels															
		-2 dB			0 dB			2 dB			4 dB			N	15 dB		
		Mean (SD)		*P*-value	Mean (SD)		*P*-value	Mean (SD)		*P*-value	Mean (SD)		*P*-value		Mean (SD)		*P*-value
		HI^	NH~		HI	NH		HI	NH		HI	NH			HI	NH	
D1[α]	HI = 13 NH = 20	0.03 (0.11)	0.17 (0.13)	$P > 0.05$	0.08 (0.13)	0.22 (0.15)	$P < 0.05$	0.12 (0.21)	0.15 (0.13)	$P > 0.05$	0.05 (0.11)	0.15 (0.12)	$P > 0.05$	HI = 33 NH = 20	0.12 (0.19)	0.00	$P < 0.05$
D2[∞]	HI = 13 NH = 20	0.14 (0.15)	0.07 (0.08)	$P > 0.05$	0.19 (0.12)	0.08 (0.08)	$P < 0.05$	0.15 (0.16)	0.09 (0.07)	$P > 0.05$	0.16 (0.14)	0.07 (0.07)	$P < 0.05$	HI = 33 NH = 20	0.14 (0.16)	0.00	$P < 0.001$
D3[β]	HI = 13 NH = 20	0.25 (0.16)	0.13 (0.08)	$P < 0.05$	0.28 (0.14)	0.09 (0.09)	$P < 0.001$	0.31 (0.22)	0.08 (0.10)	$P < 0.05$	0.36 (0.14)	0.07 (0.07)	$P < 0.001$	HI = 33 NH = 20	0.14 (0.20)	0.00	$P < 0.001$
D4[Ω]	HI = 13 NH = 20	0.14 (0.14)	0.23 (0.11)	$P < 0.05$	0.17 (0.15)	0.23 (0.11)	$P > 0.05$	0.28 (0.10)	0.15 (0.10)	$P < 0.05$	0.25 (0.10)	0.15 (0.12)	$P < 0.05$	HI = 33 NH = 20	0.12 (0.13)	0.00	$P < 0.001$

[α] PMLNT-easy minus PMLNT-hard
[∞] PDLNT-easy minus PDLNT-hard
[β] PMLNT-easy minus PDLNT-easy
[Ω] PMLNT-hard minus PDLNT-hard

DISCUSSION

The scores of the children with HL on all four subscales of the PLNTS (PMLNT-easy, PMLNT-hard, PDLNT-easy, and PDLNT-hard) were significantly less than the scores of their peers with NH (Figures 1-4). That is, the performance of the participants with HL on SWR in noise (SNR = -2 to 15 dB) was inadequate. Thus, in agreement with previous findings, school-aged children with HL experience critical difficulties in the SiN perception [6,31-38,25,27,39,40,9], specifically when they had to recognize words through auditory-only modality[41-44,24,18,45,46]. However, their SWR scores increased stepwise in the SNRs from -2 to 15 dB (Figures 1-4). Therefore, background noise should be considered a fundamental confounder affecting the listening of school-aged children with HL.

Furthermore, it should be noted that sixteen of the twenty children who used CIs could not recognize the spoken words in noise (SNR = -2 to 4 dB). More importantly, their performance was significantly lower than their peers with NH, even under optimal conditions (SNR = 15 dB). According to the findings, outcomes following cochlear implantation can be influenced by two main factors: (a) peripheral factors related to the initial sensory encoding of the speech signal into the auditory nerve and (b) central cognitive and linguistic factors such as spoken language and working memory (WM) [5-6,16,47,28,19,39,14,9]. As the PLNTs is a lexically controlled assessment toolkit independent of receptive vocabulary and spoken language competency [31,29], the lower performance of the school-aged children CIs users on SiN perception may be considered related to the semantic context O'Neill et al. [48], and WM Leibold & Buss et al. [47], as the other "top-down" processing factors. But, the words of the PLNTs were lexically adjusted for children [31,29].

Thus, the participants' poor performance may not be explained by the semantic context. In addition, according to the recent evidence on the relationship between WM and SiN perception, WM capacity was not associated with SiN performance [49], memory span did not predict variance in SiN perception [13], and cognitive training to improve WM capacity did not promote the SiN performance of children with CIs [28].

Therefore, it seems that we should look for the cause of the participants' SiN performance insufficiency in other contributing factors, including (I) poor resolving capabilities of the CI device as poor "bottom-up" processing factor [9] (II) subcortical spectrotemporal representation of speech Anderson & Kraus et al. [50], and (III) personal background factors such as the age of HL, use of residual hearing, mode of communication, and age at implantation [51,13,15,19,52].

Besides, the mean scores of the PLNTs were significantly different between the children with HL and those with NH. Although, D2 (the PDLNT-easy minus the PDLNT-hard) (0, 4, and 15 dB) and D4 (the PDLNT-hard minus the PMLNT-hard) (2, 4, and 15 dB) in the children with HL were higher than those with NH, a constant trend observed in D3 (the PDLNT-easy minus the PMLNT-easy) (-2, 0, 2, 4, and 15 dB). In addition, we did not observe the same result related to D1 (the PMLNT-easy minus the PMLNT-hard). In other words, the CIs/HAs users' scores on the PLNTs were assigned to the PDLNT-easy, the PDLNT-hard, the PMLNT-easy, and the PMLNT-hard from maximum to minimum. Therefore, although word length is an essential factor in recognizing a word both in school-aged children with HL and their peers with NH [53,36,29], similar to preschool-aged children with and without HL [24,25,27], it can be assumed that length cues, as well as spectral information in recognizing the words, were more fundamental in the children with HL than those with NH.

Therefore, similar to the school-aged children with NH, the school-aged children with HL used: (a) structural information related to familiar words organized into similar neighborhoods in long-term memory to recognize spoken words [53,36,24,25,27,29] and (b) length cues as well as spectral information in recognizing the words due to their significantly better performance in the disyllabic word recognition compared to the monosyllabic one [53,36,24,25,27,29].

Consequently, the study's findings confirmed not only our assumption that Persian school-aged children with HL have SiN perception insufficiency but also emphasized a critical condition for them to listen to spectrally degraded speech in noisy environments such as home, school, and classroom.

Further, the findings showed that the PLNTs, as a lexically controlled assessment toolkit, can differentiate the performance of Persian school-aged children with HL and those with NH on SiN perception.

CONCLUSIONS

Persian school-aged children with HL experience a critical condition related to listening spectrally degraded speech in noisy environments such as home, school, and classroom due to SiN perception insufficiency. Accordingly, they may be at risk of literacy difficulties. Therefore, it is suggested that SiN perception in school-aged CIs users be systematically assessed and monitored through valid tests to manage their listening problems in situations with background noise.

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