Research Paper

Task-specific Phonological Processing in Children With Unilateral Hearing Loss in Quiet and Noise

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Citation Kazemi T, Darouie A, Zarifian T, Ahadi M, Vahedi M. Task-specific Phonological Processing in Children With Unilateral Hearing Loss in Quiet and Noise. Iranian Rehabilitation Journal. 2026; 24(3):333-344. http://dx.doi.org/10.32598/irj.24.3.5

http://dx.doi.org/10.32598/irj.24.3.5

Article info:
Received: 24 Mar 2025
Revised: 13 May 2026
Accepted: 28 Jul 2026

Keywords:
Unilateral hearing loss (UHL), Phonological awareness, Noise, Children, Auditory perception

ABSTRACT

Objectives: Unilateral hearing loss (UHL) in children may affect phonological awareness; however, it remains unclear whether different phonological subskills are affected similarly. This study aimed to compare nonword-based phonological manipulation skills in children with UHL and normal-hearing peers across quiet and noisy conditions.

Methods: Twenty-six Persian-speaking first- and second-grade children participated, including 13 children with UHL and 13 children with normal hearing. Phonological awareness was assessed using five nonword-based subtests: blending, segmentation, and initial-, medial-, and final-phoneme deletion. Each subtest was administered under quiet and noisy conditions at a +5 dB signal-to-noise ratio. Backward digit span was assessed as a working-memory and eligibility measure. Multiple comparisons were adjusted using the Holm procedure.

Results: In first-grade children, the normal-hearing group obtained higher mean scores across all subtests, but no subtest-level between-group difference remained statistically significant after Holm correction. In second-grade children, the normal-hearing group performed significantly better in blending in noise, segmentation in both quiet and noise, and initial- and medial-phoneme deletion in noise. Significant quiet–noise differences remained for three subtests in first-grade children with UHL and four subtests in second-grade children with UHL, compared with one subtest in first-grade children with normal hearing and none in second-grade children with normal hearing. No subtest-level grade differences remained significant after correction; however, total nonword scores were higher in second-grade children with normal hearing under both listening conditions. Backward Digit Span scores did not differ significantly between the groups.

Discussion: Phonological-awareness performance was task- and grade-specific rather than uniformly impaired in children with UHL. Subtest-level between-group differences were most evident among second-grade children, particularly for tasks presented in noise. Although quiet–noise differences occurred across more subtests within the UHL groups, these findings should be interpreted cautiously because the listening-condition order was fixed and a direct group-by-condition interaction was not tested. Assessment should include multiple phonological tasks under both quiet and noisy conditions.

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Highlights

- Subtest-level between-group differences were most evident among second-grade children, particularly in noise.
- Quiet–noise differences occurred across more subtests within the UHL groups than within the normal-hearing groups.
- Phonological-awareness performance varied across tasks rather than showing one consistently vulnerable subskill.
- Assessment should include multiple phonological tasks under both quiet and noisy conditions.

Plain Language Summary

Hearing in only one ear may affect how children process and manipulate speech sounds, particularly in difficult listening situations. In this study, children with unilateral hearing loss (UHL) did not perform significantly worse on every task. Among first-grade children, none of the subtest-level group differences remained significant after statistical correction. Among second-grade children, children with normal hearing performed better on several tasks, particularly in noise. Differences between quiet and noise were observed across more tasks in the UHL groups, although the fixed testing order means that these findings should be interpreted cautiously. The results support assessing several phonological-awareness skills under both quiet and noisy conditions.

Introduction

Hearing is a fundamental sensory modality that supports the development of speech, language, and academic skills. Auditory processing involves receiving acoustic signals in the peripheral auditory system and encoding them in central auditory pathways [1, 2]. Binaural hearing enhances speech perception, particularly in noisy environments, through mechanisms, such as binaural summation, the head shadow effect, and release from masking [3].

Unilateral hearing loss (UHL), defined as normal hearing (≤15 dB HL) in one ear and sensorineural hearing loss in the contralateral ear, reduces the benefits of binaural processing [4, 5]. Although one normal-hearing ear was previously considered sufficient for typical development, evidence indicates that children with UHL are at risk for delays in speech and language development, as well as deficits in auditory processing and academic performance [6–8]. Children with UHL also demonstrate poorer performance in speech perception in noise, temporal auditory processing, and phonological and language-related tasks [4, 9, 10].

Phonological awareness is a core skill underlying language development and early reading acquisition and depends on precise and stable auditory input [11]. Disruptions in auditory input, especially under noisy conditions, may impair the formation of stable phonological representations and increase reliance on cognitive resources such as working memory [12, 13]. Children with UHL have demonstrated difficulties in temporal auditory processing [4, 10], and temporal-processing limitations may negatively affect phonological awareness skills, including phoneme identification and manipulation [14].

Nonword-based tasks are sensitive measures of phonological processing because they require the encoding, temporary storage, and manipulation of novel sound sequences with minimal support from lexical knowledge [15]. Previous studies have also reported poorer speech perception in noise in children with UHL [16, 17], as well as difficulties in phonological, vocabulary, and broader language outcomes [18, 19]. One study further showed that children with UHL had greater difficulty with novel-word learning, particularly under noisy listening conditions [20]. However, it remains unclear which levels of phonological manipulation are most affected.

Accordingly, the present study aimed to compare different phonological manipulation subskills across listening conditions and grade levels in children with UHL and their normal-hearing peers.

Materials and Methods

Study design and participants

This comparative cross-sectional study included 26 Persian-speaking first- and second-grade children aged 6-8 years in Tehran, Iran. Participants were divided into two hearing-status groups: children with UHL (n=13) and normal-hearing peers (NH; n=13). Each participant completed five nonword-based phonological awareness subtests under both noise and quiet listening conditions. Analyses were conducted at three levels: 1) comparisons between the UHL and NH groups within each grade and listening condition; 2) comparisons between first- and second-grade children within each hearing-status group and listening condition; and 3) within-participant comparisons between noise and quiet conditions within each grade and hearing-status group.

Sample size estimation

Sample size was calculated using G*Power software, version 3.1, assuming an effect size of d=0.8, α=0.05, and power=0.8. The minimum required sample size was 13 participants per hearing-status group, for a total of 26 participants.

Inclusion and exclusion criteria

Participants were Persian-speaking children with congenital or early-acquired unilateral sensorineural hearing loss before age 2. Children in the UHL group had hearing thresholds greater than 41 dB HL in the affected ear and ≤15 dB HL in the contralateral ear. Children who used hearing aids were excluded to reduce heterogeneity associated with amplification history, device fitting, duration and consistency of use, and aided audibility. Other exclusion criteria included neurological disorders, autism spectrum disorder, attention-deficit/hyperactivity disorder, intellectual disability, and visual impairment. Participants with a backward digit span of two digits or greater were eligible for inclusion, whereas those with a span below two digits were excluded. The NH group met the same eligibility criteria but had bilateral hearing thresholds ≤15 dB HL.

Procedures

After obtaining ethical approval and written parental consent, demographic, medical, and audiological information was collected. The Backward Digit Span test was administered before the phonological awareness assessment. Testing was conducted in a 12 m² classroom-like room. The quiet condition was not treated as a baseline. The fixed order was selected to prevent task-related fatigue from disproportionately affecting performance under the more demanding noise condition. However, because the order was not counterbalanced, possible practice, stimulus-familiarity, and order effects cannot be excluded. Therefore, comparisons between noise and quiet conditions should be interpreted cautiously.

In the noise condition, standardized Persian eight-talker babble noise was presented from the two lateral loudspeakers, while the test stimuli were presented from the front loudspeaker. Speech and noise were presented at 65 dB SPL and 60 dB SPL, respectively, resulting in a signal-to-noise ratio of +5 dB [16, 17, 21]. Three loudspeakers were positioned at 0°, +90°, and −90° relative to the child [16]. The distance between the child and each loudspeaker was 1 meter, and the loudspeakers were positioned at ear level. Sound levels were calibrated using a Type 1 sound level meter [22]. In the quiet condition, only the front loudspeaker was active, and ambient noise was maintained below 40 dB [23]. All test stimuli were prerecorded to control for visual and intensity-related cues. The total testing time was approximately 45–60 minutes.

Nonword development

The nonwords were developed based on the Solimani-Dastjerdi test under the supervision of two speech-language pathologists who were university faculty members with more than 20 years of experience working with children with hearing loss. The items followed Persian phonotactic rules and matched the original test items in structure and complexity. Items considered inappropriate or ambiguous were revised or replaced based on the experts' comments. The final set included 50 nonwords with CV, CVC, and CVCC structures, most of which were one or two syllables in length (Supplementary Appendix).

Scoring

Responses were scored dichotomously as 0 (incorrect) or 1 (correct). A response was considered correct when the target phoneme sequence was produced without omission, substitution, or transposition errors. Failure to respond within 10 seconds was scored as incorrect. Each item could be replayed once at the child's request. All responses were recorded and independently rescored by a second speech-language pathologist who was blinded to group allocation. Inter-rater reliability was assessed using an intraclass correlation coefficient (ICC) based on a two-way random-effects model for absolute agreement.

Table 1. Demographic characteristics (n=13)

Group		No. (%)	
Characteristics	**Variables**	**UHL**	**NH**
Degree of hearing loss	Moderate to severe	5(38.5)	
	Severe to profound	8(61.5)	
Affected ear	Right ear	6(46.2)	
	Left ear	7(53.8)	
Gender	Male	6(46.2)	7(53.8)
	Female	7(53.8)	6(46.2)
Grade level	1st	6(46.2)	6(46.2)
	2nd	7(53.8)	7(53.8)
Age	7 years (6 y, 12 m)	6(46.2)	6(46.2)
	8 years (7 y, 12 m)	7(53.8)	7(53.8)

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Note: Degree of hearing loss classification is based on the most recent audiogram: Moderate to severe= 41-70 dB HL; Severe to profound=71 dB HL or greater. Age categories: 7 years=6 years and 12 months and above; 8 years=7 years and 12 months and above.

Statistical analysis

Data were analyzed using SPSS software, version 27. Normality was assessed using the Shapiro–Wilk test; for quiet–noise comparisons, normality was evaluated based on the difference scores. Independent-samples t-tests, Welch's t-tests, or Mann–Whitney U tests were used for between-group and between-grade comparisons, whereas paired-samples t-tests or Wilcoxon signed-rank tests were used for within-participant comparisons. Exact two-sided P values were reported for nonparametric tests. Holm correction was applied within each prespecified family of comparisons, with total-score comparisons corrected separately. Statistical significance was set at Holm-adjusted $P<0.05$. Effect sizes were reported uniformly as r. For parametric comparisons, r was calculated as Equation 1:

1. $\sqrt{[t^2/(t^2 + df)]}$,

whereas for Mann–Whitney U and Wilcoxon signed-rank tests, r was calculated as Equation 2:

2. $|Z|/\sqrt{N}$,

where N represented the total number of observations for independent-group comparisons and the number of paired observations for within-participant comparisons.

Results

The UHL and NH groups were comparable in terms of age and grade distribution. In the UHL group, eight children (61.5%) had severe-to-profound hearing loss, and five children (38.5%) had moderate-to-severe hearing loss. The affected ear was the right ear in six children (46.2%) and the left ear in seven children (53.8%) (Table 1).

Descriptively, mean scores were generally higher in the NH group than in the UHL group across the phonological awareness subtests. Within both hearing-status groups, second-grade children generally obtained higher mean scores than first-grade children, and mean scores were higher under the quiet condition than under the noise condition. Several subtests showed near-ceiling performance in the NH group under the quiet condition, whereas the UHL group showed greater variability. Medial-phoneme deletion had the lowest mean scores in several group and condition combinations, indicating that it was descriptively one of the most difficult tasks. Mean scores were generally higher in quiet than in noise in both hearing-status groups; the corresponding within-group comparisons are reported below.

Supplementary Table S1 presents Shapiro–Wilk normality test results for all phonological awareness outcomes and quiet–noise difference scores. Parametric or nonparametric tests were selected accordingly.

UHL vs NH comparisons by grade and listening condition

In first-grade children, segmentation and final-phoneme deletion in quiet were analyzed using Mann–Whitney U tests, initial-phoneme deletion in noise using Welch's t-test, and the remaining subtest comparisons using independent-samples t-tests. The NH group obtained higher mean scores across all subtests. Although several raw subtest comparisons were significant, none of the ten subtest comparisons remained statistically significant after Holm correction (adjusted P=0.070–0.344; r=0.42–0.73). In contrast, total nonword scores were significantly higher in the NH group under both the noise condition (adjusted P=0.006, r=0.78) and the quiet condition (adjusted P=0.006, r=0.75).

In second-grade children, the NH group obtained higher mean scores across all subtests. After Holm correction, significant between-group differences remained for blending in noise, segmentation in both noise and quiet, initial-phoneme deletion in noise, and medial-phoneme deletion in noise (adjusted P<0.05; r=0 .71–0.87). The remaining five subtest comparisons were not statistically significant after correction. The total nonword scores were significantly higher in the NH group under both the noise condition (adjusted P<0.002, r=0.84) and quiet condition (adjusted P=0.006, r=0.71) (Table 2).

First- vs second-grade comparisons within hearing groups

In the UHL group, no significant differences were found between first- and second-grade children across either the phonological awareness subtests or the total nonword scores after Holm correction.

In the NH group, none of the subtest-level differences between first- and second-grade children remained statistically significant after Holm correction. However, total nonword scores were significantly higher in second-grade children under both noise and quiet conditions (Holm-adjusted P=0.002 and 0.003, respectively) (Table 3).

Quiet vs noise comparisons by hearing group and grade

In the UHL group, first-grade children obtained significantly higher scores in quiet than in noise for blending, medial-phoneme deletion, and final-phoneme deletion after Holm correction (adjusted P=0.020, <0.005, and 0.036, respectively). Differences in segmentation and initial-phoneme deletion were not statistically significant after correction. In second-grade children, significant quiet–noise differences remained for blending, segmentation, medial-phoneme deletion, and final-phoneme deletion, with Holm-adjusted P ranging from <0.005 to 0.048, whereas initial-phoneme deletion was not significant. The significant comparisons showed large effect sizes (r=0.8–0.96).

In the NH group, first-grade children showed a significant quiet–noise difference only for blending after Holm correction (adjusted P=0.005, r=0.94). In second-grade children, none of the quiet–noise comparisons remained statistically significant after correction, although large effect sizes were observed for blending, segmentation, and medial-phoneme deletion (r=0.71–0.88).Total nonword scores were also significantly higher in quiet than in noise in both grades and hearing-status groups, with Holm-adjusted P ranging from <0.001 to 0.005 and large effect sizes (r=0.89–0.96) (Table 4).

Inter-rater reliability

To assess inter-rater scoring reliability, the test was recorded for each child, and the second rater was blinded to group allocation. The ICC was then calculated using a two-way random effects model for absolute agreement. The ICC for nonwords in noise was 0.950 (95% confidence interval [CI], 0.851%, 0.984%, P<0.001) and for nonwords in the quiet condition was 0.950 (95% CI, 0.851%, 0.984%, P<0.001). The results indicated that both ICC values were in the excellent range, demonstrating very high inter-rater reliability.

Digit span scores

The mean backward digit span score was 2.23±0.44 in the NH group and 2.15±0.38 in the UHL group. Backward digit span scores were not significantly different between the two groups (Mann–Whitney U=78, Z=−0.488, exact P=1.000, r=0.1).

Discussion

Phonological awareness is a key component of language development and depends partly on accurate auditory input. This study examined nonword-based phonological-awareness performance across tasks with different phonological demands, under quiet and noise conditions, in children with UHL and their peers with NH [1, 5, 15].

Table 2. Comparisons of phonological-awareness performance between the UHL and NH groups by grade and listening condition

Grade	Subtest	Condition	Mean±SD		Test	t/U	Raw P	Holm-Adjusted P	Effect Size (r)
			UHL	NH					
1st	Blending	Noise	0.816±2.67	2.366±5	t-test	2.283	0.046	0.230	0.59
1st	Blending	Quiet	5.83±1.472	7.67±1.966	t-test	1.828	0.097	0.320	0.5
1st	Segmentation	Noise	0.816±3.33	1.941±5.83	t-test	2.908	0.016	0.128	0.68
1st	Segmentation	Quiet	4.83±1.169	7.17±1.329	Mann-Whitney	3	0.009	0.081	0.71
1st	Initial phoneme deletion	Noise	3.83±1.169	6.33±2.733	Welch t-test	2.06	0.080	0.320	0.62
1st	Initial phoneme deletion	Quiet	4.5±1.379	7.50±2.43	t-test	2.631	0.025	0.154	0.64
1st	Medial phoneme deletion	Noise	1.378±3.5	1.789±6	t-test	2.712	0.022	0.154	0.65
1st	Medial phoneme deletion	Quiet	5.5±1.225	6.67±1.506	t-test	1.472	0.173	0.344	0.42
1st	Final phoneme deletion	Noise	1.095±7	0.753±8.83	t-test	3.379	0.007	0.070	0.73
1st	Final phoneme deletion	Quiet	8.83±0.408	9.33±0.516	Mann-Whitney	10	0.273	0.344	0.49
1st	Total_nonword	Noise	20.33±3.502	32.00±6.26	t-test	3.98	0.003	0.006	0.78
1st	Total_nonword	Quiet	29.5±3.782	38.33±4.64	t-test	3.61	0.005	0.006	0.75
2nd	Blending	Noise	4.43±1.813	8.43±1.134	t-test	4.95	<0.001	0.003	0.82
2nd	Blending	Quiet	8±1.915	9.57±0.787	Mann-Whitney	13.5	0.135	0.270	0.42
2nd	Segmentation	Noise	4±1.414	8.29±1.254	t-test	6	<0.001	<0.001	0.87
2nd	Segmentation	Quiet	6.57±1.618	9.14±0.9	t-test	3.674	0.003	0.025	0.73
2nd	Initial phoneme deletion	Noise	5.43±2.44	9.14±1.215	Mann-Whitney	3.5	0.006	0.036	0.73
2nd	Initial phoneme deletion	Quiet	6.57±3.101	9.71±0.488	Mann-Whitney	6.5	0.025	0.100	0.65
2nd	Medial phoneme deletion	Noise	3.84±1.574	6.43±1.134	t-test	3.508	0.004	0.03	0.71
2nd	Medial phoneme deletion	Quiet	6.14±1.864	7.71±0.951	t-test	1.986	0.070	0.21	0.5
2nd	Final phoneme deletion	Noise	7.43±1.618	9.29±0.756	t-test	2.751	0.018	0.088	0.62
2nd	Final phoneme deletion	Quiet	9±0.577	9.43±0.535	Mann-Whitney	15.5	0.364	0.36	0.36
2nd	Total_nonword	Noise	25.14±4.25	41.57±2.57	Mann-Whitney	0	<0.001	<0.002	0.84
2nd	Total_nonword	Quiet	36.28±7.22	45.57±1.98	Mann-Whitney	4	0.006	0.006	0.71

UHL: Unilateral hearing loss; NH: Normal hearing.

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Note: Welch's t-test was used when the assumption of equal variances was violated, and the Mann–Whitney U test was used when the normality assumption was not met. Effect sizes are reported as r. Raw and Holm-adjusted two-sided P are presented. Bold values indicate statistical significance after Holm correction (P<0.05).

Table 3. Comparisons of phonological-awareness performance between first- and second-grade children within each hearing-status group

Group	Subtest	Condition	Mean±SD		Test	t/U	Raw P	Holm-adjusted P	Effect Size (r)
			FG	SG					
UHL	Blending	Noise	0.816±2.67	1.813±4.43	t-test	2.188	0.051	0.51	0.55
UHL	Blending	Quiet	5.83±1.472	8±1.915	Mann-Whitney	8	0.067	0.594	0.52
UHL	Segmentation	Noise	0.816±3.33	1.414±4	t-test	1.015	0.332	1.000	0.29
UHL	Segmentation	Quiet	4.83±1.169	6.57±1.618	Mann-Whitney	8	0.066	0.594	0.53
UHL	Initial phoneme deletion	Noise	3.83±1.169	5.43±2.44	Welch t-test	1.536	0.159	1.000	0.46
UHL	Initial phoneme deletion	Quiet	4.5±1.379	6.57±3.101	t-test	1.506	0.16	1.000	0.41
UHL	Medial phoneme deletion	Noise	1.378±3.5	1.574±3.86	t-test	0.431	0.675	1.000	0.13
UHL	Medial phoneme deletion	Quiet	5.5±1.225	6.14±1.864	t-test	0.72	0.487	1.000	0.21
UHL	Final phoneme deletion	Noise	1.095±7	1.618±7.43	t-test	0.548	0.594	1.000	0.16
UHL	Final phoneme deletion	Quiet	8.83±0.408	9±0.577	Mann-Whitney	18	0.755	1.000	0.16
UHL	Total_non-word	Noise	20.33±3.502	25.14±4.25	t-test	2.198	0.05	0.100	0.55
UHL	Total_non-word	Quiet	29.50±3.782	36.28±7.22	t-test	2.062	0.064	0.100	0.53
NH	Blending	Noise	5±2.366	8.43±1.134	t-test	3.42	0.006	0.060	0.72
NH	Blending	Quiet	7.67±1.966	9.57±0.787	Mann-Whitney	9	0.066	0.330	0.52
NH	Segmentation	Noise	5.83±1.941	8.29±1.254	t-test	2.75	0.019	0.152	0.64
NH	Segmentation	Quiet	7.17±1.329	9.14±0.9	t-test	3.184	0.009	0.081	0.69
NH	Initial phoneme deletion	Noise	6.33±2.733	9.14±1.215	Mann-Whitney	6	0.03	0.210	0.61
NH	Initial phoneme deletion	Quiet	7.5±2.429	9.71±0.488	Mann-Whitney	6.5	0.04	0.240	0.61
NH	Medial phoneme deletion	Noise	6±1.789	6.43±1.134	t-test	0.525	0.61	1.000	0.16
NH	Medial phoneme deletion	Quiet	6.67±1.506	7.71±0.951	t-test	1.525	0.155	0.620	0.42
NH	Final phoneme deletion	Noise	8.83±0.753	9.29±0.756	t-test	1.078	0.304	0.912	0.31
NH	Final phoneme deletion	Quiet	9.33±0.516	9.43±0.535	Mann-Whitney	19	1	1.000	0.09
NH	Total_non-word	Noise	32±6.26	41.57±2.57	Mann-Whitney	0	0.001	0.002	0.84
NH	Total_non-word	Quiet	38.33±4.63	45.57±1.98	Mann-Whitney	1.5	0.003	0.003	0.78

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Abbreviations: UHL: Unilateral hearing loss; NH: Normal hearing; FG; First grade; SG: Second grade.

Note: Independent-samples t-tests were used when parametric assumptions were met, and Welch's -test was used when the assumption of equal variances was violated. Mann–Whitney U tests were used when the normality assumption was violated. Effect sizes are reported as r. Raw and Holm-adjusted two-sided P are presented. Bold values indicate statistical significance after Holm correction (adjusted P<0.05). Absolute t values are reported, and the direction of the differences is indicated by the descriptive statistics.

Table 4. Within-participant comparisons of phonological-awareness performance between quiet and noise conditions by hearing-status group and grade

Group	Grade	Subtest	Mean±SD	Statistical Test	t or |Z|	Raw P	Holm-Adjusted P	Effect Size (r)
UHL	1st	PB	3.167±1.602	Paired t-test	4.842	0.005	0.020	0.91
UHL	1st	PS	1.5±1.378	Paired t-test	2.666	0.045	0.090	0.77
UHL	1st	IPD	0.666±0.516	Wilcoxon	2.000	0.125	0.125	0.82
UHL	1st	MPD	2±0.632	Paired t-test	7.746	<0.001	<0.005	0.96
UHL	1st	FPD	1.833±1.169	Paired t-test	3.841	0.012	0.036	0.86
UHL	1st	Total	9.166±3.92	Paired t-test	5.728	0.002	0.005	0.93
UHL	2nd	PB	3.571±1.512	Paired t-test	6.25	<0.001	<0.005	0.93
UHL	2nd	PS	2.571±0.534	Wilcoxon	2.428	0.016	0.048	0.92
UHL	2nd	IPD	1.143±2.193	Paired t-test	1.379	0.217	0.217	0.49
UHL	2nd	MPD	2.286±1.496	Paired t-test	4.042	0.007	0.028	0.86
UHL	2nd	FPD	1.571±1.272	Paired t-test	3.267	0.017	0.048	0.80
UHL	2nd	Total	11.142±3.436	Paired t-test	8.579	<0.001	<0.001	0.96
NH	1st	PB	2.667±1.033	Paired t-test	6.325	0.001	0.005	0.94
NH	1st	PS	1.333±1.211	Paired t-test	2.697	0.043	0.172	0.77
NH	1st	IPD	1.167±1.169	Paired t-test	2.445	0.058	0.172	0.74
NH	1st	MPD	0.666±1.211	Wilcoxon	1.342	0.500	0.500	0.55
NH	1st	FPD	0.5±0.5477	Wilcoxon	1.732	0.250	0.500	0.71
NH	1st	Total	6.333±2.25	Paired t-test	6.892	0.001	0.003	0.95
NH	2nd	PB	1.142±0.899	Wilcoxon	2.333	0.031	0.124	0.88
NH	2nd	PS	0.857±0.69	Paired t-test	3.286	0.017	0.085	0.8
NH	2nd	IPD	0.571±0.975	Wilcoxon	1.414	0.500	1.000	0.53
NH	2nd	MPD	1.286±1.38	Paired t-test	2.465	0.049	0.147	0.71
NH	2nd	FPD	0.142±0.377	Wilcoxon	1	1.000	1.000	0.38
NH	2nd	Total	4±2.236	Paired t-test	4.733	0.003	0.005	0.89

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Abbreviation: UHL: Unilateral hearing loss; NH: Normal hearing; PB: Phoneme blending; PS: Phoneme segmentation; IPD: Initial-phoneme deletion; MPD: Medial-phoneme deletion; FPD: Final-phoneme deletion.

Note: Positive values indicate higher performance in quiet than in noise. Paired-samples t-tests were used when the difference scores met the normality assumption, and Wilcoxon signed-rank tests were used otherwise. Paired-samples t statistics and absolute Wilcoxon Z values are reported. Effect sizes are reported as r. Raw and Holm-adjusted two-sided P are presented. Bold values indicate statistical significance after Holm correction (adjusted P<0.05).

Between-group differences were task- and grade-specific. In first-grade children, the NH group obtained higher mean scores across all subtests, although none of the subtest-level differences remained statistically significant after Holm correction. In second-grade children, the NH group performed significantly better in blending in noise, segmentation in both conditions, and initial- and medial-phoneme deletion in noise. Total nonword scores were also significantly higher in the NH group under both listening conditions in both grades. These findings are consistent with previous reports of speech-perception and word-learning difficulties in children with UHL, particularly under adverse listening conditions [3, 16, 20]. Because nonword tasks reduce reliance on lexical familiarity, the observed differences may reflect difficulties in processing unfamiliar phonological information rather than lexical knowledge alone [15, 21]. Several first-grade comparisons nevertheless yielded moderate-to-large effect-size estimates; given the small subgroup sizes and nonsignificant Holm-adjusted P, these estimates should be interpreted as imprecise descriptive indicators rather than evidence of reliable group differences.

Backward digit span scores did not differ significantly between the groups, suggesting that a general difference in working-memory span did not account for the observed pattern. However, variability in hearing-loss severity and other auditory, cognitive, or linguistic factors may have contributed to individual differences [12, 13]. Performance also varied across tasks. Medial-phoneme deletion produced the lowest mean scores in several group and condition combinations and was descriptively among the most difficult tasks. Among second-grade children, initial- and medial-phoneme deletion in noise differentiated the UHL and NH groups, whereas final-phoneme deletion did not remain significant after correction. Thus, hearing status and listening condition were not associated with a uniform pattern across phonological-awareness tasks [11].

At the subtest level, significant quiet–noise differences were more frequent in the UHL group. First-grade children with UHL performed significantly better in quiet for blending and medial- and final-phoneme deletion, whereas second-grade children with UHL showed significant differences for blending, segmentation, and medial- and final-phoneme deletion. In the NH group, only blending remained significant in first-grade children, and no subtest-level comparison remained significant in second-grade children. Total nonword scores, however, were significantly higher in quiet than in noise in both grades and both hearing-status groups. Nevertheless, because the listening-condition order was fixed and a direct group-by-condition interaction was not tested, the present findings do not establish that noise affected the UHL group significantly more than the NH group. No subtest-level difference between first- and second-grade children remained significant within either hearing-status group; only total nonword scores in the NH group were significantly higher in second-grade children under both listening conditions. These cross-sectional findings should therefore not be interpreted as evidence of developmental change over time [7, 8, 19].

Clinically, the findings support assessing phonological awareness using multiple tasks under both quiet and noise conditions, because performance differences were not uniform across subtests. Educational planning may also benefit from explicit phonological-awareness support and reduced background noise in classroom environments [23]. The main limitations were the small grade-specific samples, variability in hearing-loss severity, the fixed noise-first test order, the cross-sectional design, and the exclusion of children using hearing aids, which limits generalizability to aided children with UHL. Future studies should include larger and more homogeneous samples, counterbalance listening-condition order, directly examine group-by-condition interactions, and further investigate auditory, cognitive, and linguistic contributions to phonological processing [13, 14].

Conclusion

The findings indicate that nonword-based phonological-awareness performance in children with UHL differs according to task demands, grade, and listening condition. At the subtest level, between-group differences were concentrated in second-grade children and were particularly evident for tasks presented in noise; no first-grade subtest-level comparison remained significant after Holm correction. However, total nonword scores were significantly higher in the NH group under both listening conditions in both grades. Quiet–noise differences were more frequent in the UHL group at the subtest level, whereas total scores were significantly higher in quiet across all four grade-by-hearing-status subgroups. Because the test order was fixed and no direct group-by-condition interaction was examined, these findings require cautious interpretation. Overall, the results support using varied phonological-awareness tasks under different listening conditions and highlight the importance of improving auditory access in educational and clinical settings.

Ethical Considerations

Compliance with ethical guidelines

this study was approved by the Research Ethics Committee of the University of Social Welfare and Rehabilitation Sciences, Tehran, Iran (Code: IR.USWR.REC.1403.119). Informed consent was obtained from all participants.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Authors' contributions

Conceptualization: Tarane Kazemi, Akbar Darouie, Talieh Zarifian and Mohsen Ahadi; Methodology: Akbar Darouie and Mohsen Vahedi; Investigation: Tarane Kazemi, Akbar Darouie and Talieh Zarifian; Writing the original draft: Tarane Kazemi; Review and editing: Akbar Darouie and Talieh Zarifian; Resources and supervision: Akbar Darouie, Talieh Zarifian and Mohsen Ahadi.

Conflict of interest

The authors declared no conflict of interest.

Acknowledgments

The authors thank Nasrin Yazdani, Parvaneh Mahdi, the parents of the children, school principals, colleagues including Zeinab Barati and Arsham Neshati, and all individuals who assisted in the implementation and sampling process.

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Supplementary Appendix 1.

Nonword stimuli used in the phonological awareness tasks

(blending, segmentation, initial, medial, final phoneme deletion)

This appendix provides the list of Persian nonwords constructed

according to Persian phonotactic rules and reviewed by two independent speech-language pathologists.

Table S1. Nonword stimuli used in the five phonological awareness subtests.

ردیف	ترکیب واجی	نویز	سکوت	تقطیع واجی	نویز	سکوت	حذف واج آغازین	نویز	سکوت
	گویه	نمره	نمره	گویه	نمره	نمره	گویه	نمره	نمره
۱	پو			دا			دا		
۲	کاف			ساب			شِب		
۳	دَل			نَن			لِک		
۴	تَشم			کوفش			تِشم		
۵	جیرو			تَرخ			هَسب		
۶	شانو			قَری			جاجه		
۷	قایچی			جیجه			کُتوب		
۸	کِژتی			کُلوه			نِسویک		
۹	بَندان			مسویک			پیوز		
۱۰	کِبروت			گوشمند			دِپُخت		

ردیف	حذف واج میانی	نویز	سکوت	حذف واج پایانی	نویز	سکوت
	گویه	نمره	نمره	گویه	نمره	نمره
۱	/بورگ/ر			پون		
۲	/چاتر/ت			کوپ		
۳	/هَسب/س			شی		
۴	/گاهی/ه			پاه		
۵	/خاسِه/س			گیو		
۶	/میاز/ی			سوعَت		
۷	/دُختور/خ			هواج		
۸	/قوسفمد/ف			قوچی		
۹	/لیک پاشت/ک			بورگ		
۱۰	/تَفشدیزک/د			خاده		