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Research Article

Predictors of symptom score improvement in pediatric otolaryngology patients with sensorineural hearing loss

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Abstract

Background: Sensorineural hearing loss (SNHL) affects roughly 1-3 per 1,000 children and is managed with hearing aids or cochlear implantation alongside early-intervention services, yet clinic-level predictors of short-term symptom improvement remain incompletely characterized.

Objective: To identify predictors of clinically meaningful improvement in a composite otologic-communication symptom score during the 12 months after diagnosis of pediatric SNHL.

Methods: Retrospective cohort of 214 children aged 0-8 years newly diagnosed with SNHL across three tertiary otolaryngology divisions, 2018-2023. Symptom scores (0-100) were recorded at diagnosis and 12 months; multivariable logistic regression identified predictors of a ≥ 15 -point reduction.

Results: Mean symptom score fell from 61.4 to 38.9 (reduction 22.5 points, $p < 0.001$); 63.1% met the improvement threshold. Independent predictors included intervention before 12 months of age (aOR 3.42, 95% CI 1.86-6.29), bilateral device fitting (aOR 2.28, 95% CI 1.24-4.19), early-intervention enrollment within 60 days (aOR 2.71, 95% CI 1.49-4.93), absence of comorbid developmental disability (aOR 2.14, 95% CI 1.12-4.08), and cochlear implantation over hearing aids in severe-to-profound loss (aOR 2.02, 95% CI 1.05-3.89).

Conclusions: Early intervention timing, bilateral device access, prompt early-intervention enrollment, and absence of comorbid developmental disability were the strongest independent predictors of symptom improvement in pediatric SNHL.

Keywords: sensorineural hearing loss; pediatric otolaryngology; cochlear implantation; early intervention; symptom score

1. Introduction

Sensorineural hearing loss (SNHL) is among the most common sensory impairments identified in childhood, affecting roughly 1 to 3 per 1,000 live births and rising further when late-onset and progressive cases are included [1,2]. Since the widespread adoption of universal newborn hearing screening, most children with congenital SNHL are identified within the first months of life, but identification alone does not translate into improved communication or otologic symptom burden unless it is followed promptly by audiologic intervention, whether hearing aid amplification or cochlear implantation, and by structured early-intervention services [3,4]. Professional guidance from the Joint Committee on Infant Hearing and the American Academy of Pediatrics has progressively shortened the recommended interval between screening, diagnostic confirmation, and intervention enrollment in recognition of this gap [2,5], yet clinicians managing these children in tertiary otolaryngology practice continue to see wide variability in how quickly, and how completely, symptoms improve after diagnosis.

A large body of evidence links intervention timing to downstream language outcomes. Kennedy and colleagues, following a UK cohort with permanent childhood hearing impairment, found that children detected through newborn screening had significantly better language scores at 7 to 8 years than those detected later by clinical suspicion [6]. The Longitudinal Outcomes of Children with Hearing Impairment (LOCHI) study similarly demonstrated that earlier intervention, particularly before 12 months of age, predicted better language outcomes at 3 and 5 years, with a nonlinear dose-response relationship across the first three years of life [7,8]. Cochlear implant outcome studies reinforce the same pattern at the device level: Niparko and colleagues, in the multicenter Childhood Development after Cochlear Implantation (CDaCI) study, found that younger age at implantation was independently associated with steeper

spoken-language growth [9], and Tomblin and colleagues reported comparable age-dependent gains among children implanted before versus after 24 months [10].

Beyond age at intervention, laterality and symmetry of device fitting, etiology and severity of hearing loss, enrollment in early-intervention services, and additional developmental disabilities have also been proposed as outcome predictors. Bilateral cochlear implantation has been associated with faster language development than unilateral implantation [11], while unilateral or asymmetric hearing loss, even when mild, has been linked to worse speech-language outcomes than bilateral symmetric loss of comparable severity [12,13]. Children with additional developmental disabilities consistently show slower, more variable progress after intervention than developmentally typical peers with SNHL, complicating outcome prediction in mixed clinical populations [14,15]. Most of this literature, however, has focused on speech and language test scores over multi-year horizons, leaving a narrower evidence base on the short-term, clinic-relevant predictors captured by composite symptom scores increasingly used in routine otolaryngology follow-up.

This study examines predictors of clinically meaningful improvement in a composite symptom score during the first 12 months after diagnosis of pediatric SNHL in a multicenter tertiary otolaryngology cohort. We hypothesized that earlier intervention, bilateral device fitting, prompt early-intervention enrollment, and absence of comorbid developmental disability would each independently predict symptom improvement, consistent with the longer-horizon language-outcome literature.

2. Methods

We conducted a retrospective cohort study of children aged 0 to 8 years newly diagnosed with bilateral or unilateral sensorineural hearing loss at three tertiary pediatric otolaryngology divisions between January 2018 and December 2023. Eligible children had a confirmed

diagnosis of permanent SNHL on diagnostic auditory brainstem response or behavioral audiometry, at least one audiologic intervention (hearing aid fitting or cochlear implantation) initiated during the study period, and a documented symptom score at diagnosis and again at 12 months. Children with conductive or mixed hearing loss as the primary diagnosis, those lost to follow-up before 12 months, and those without a baseline score were excluded, leaving a final analytic cohort of 214 children.

The primary outcome was the composite otologic-communication symptom score, a clinician- and caregiver-completed instrument used across all three sites that scores otologic symptoms, listening effort, and functional communication difficulty on a 0 to 100 scale, with higher scores indicating greater symptom burden, consistent in structure with validated pediatric hearing-related quality-of-life instruments used in this population [16,17]. Clinically meaningful improvement was defined a priori as a reduction of 15 points or more, a threshold selected to exceed the instrument's estimated measurement variability while remaining achievable within a year of intervention.

Candidate predictors, chosen from the early-intervention and cochlear implant outcomes literature, included age at intervention initiation (under 12 months, 12 to 36 months, over 36 months) [8,9], degree of hearing loss by pure-tone average in the better ear (moderate, severe, profound), laterality of hearing loss and symmetry of device fitting, device type (hearing aid only versus cochlear implantation), etiology (genetic, congenital non-genetic/other, acquired or unknown), time from diagnosis to early-intervention enrollment (within 60 days versus later) [18,19], and presence of a comorbid developmental disability [15,14]. Demographic covariates included sex, maternal education, and household language concordance with the clinical setting.

Continuous variables were compared using two-sample t-tests and categorical variables using chi-square tests.

Multivariable logistic regression identified independent predictors of clinically meaningful improvement, with all candidate predictors entered simultaneously and results reported as adjusted odds ratios (aOR) with 95% confidence intervals; model discrimination was assessed by the area under the receiver operating characteristic curve. Two-sided p-values below 0.05 were considered significant. Institutional review board approval was obtained at each site with a waiver of individual consent for this retrospective analysis.

3. Results

Of 214 children in the analytic cohort, 118 (55.1%) were male, and mean age at diagnosis was 18.4 months (SD 21.6). Hearing loss was bilateral in 171 children (79.9%) and unilateral in 43 (20.1%); severity was moderate in 61 (28.5%), severe in 76 (35.5%), and profound in 77 (36.0%). A genetic etiology was identified in 84 children (39.3%), congenital non-genetic or other causes in 71 (33.2%), and acquired or undetermined causes in 59 (27.6%). Intervention was hearing aid amplification alone in 132 children (61.7%) and cochlear implantation in 82 (38.3%); 96 children (44.9%) received bilateral devices. Enrollment in early-intervention services occurred within 60 days of diagnosis in 128 children (59.8%). A comorbid developmental disability was documented in 47 children (22.0%).

Mean symptom score fell from 61.4 (SD 14.2) at diagnosis to 38.9 (SD 17.8) at 12 months, a mean within-child reduction of 22.5 points (95% CI 20.1-24.9, $p < 0.001$). Overall, 135 of 214 children (63.1%) met the threshold for clinically meaningful improvement (score reduction ≥ 15 points), while 49 (22.9%) showed a reduction of less than 15 points and 30 (14.0%) showed no improvement or worsening.

Bivariate comparisons showed larger score reductions among children intervened before 12 months of age than among those intervened later, among children fitted with bilateral devices compared with unilateral fitting, and

among children without a comorbid developmental disability (Figure 1). The proportion meeting the clinically meaningful improvement threshold also varied by device type and by timeliness of early-intervention enrollment (Table 1).

Table 1: Baseline characteristics of the 214-child cohort by 12-month symptom improvement status.			
Characteristic	Improved (n=135)	Not improved (n=79)	p-value
Age at intervention <12 months	71 (52.6%)	18 (22.8%)	<0.001
Bilateral device fitting	70 (51.9%)	26 (32.9%)	0.007
Early-intervention enrollment <=60 days	91 (67.4%)	37 (46.8%)	0.002
Comorbid developmental disability	20 (14.8%)	27 (34.2%)	0.001
Cochlear implantation (severe-to-profound loss)	56 (41.5%)	20 (25.3%)	0.015

Predictors of intervention timing and device selection

In multivariable logistic regression, intervention before 12 months of age was independently associated with clinically meaningful improvement relative to intervention after 36 months (aOR 3.42, 95% CI 1.86-6.29, p<0.001), and intervention between 12 and 36 months showed an intermediate, non-significant association (aOR 1.61, 95% CI 0.89-2.92, p=0.11). Bilateral device fitting was independently associated with improvement relative to unilateral fitting (aOR 2.28, 95% CI 1.24-4.19, p=0.008). Among children with severe-to-profound loss, cochlear implantation was independently associated with greater odds of improvement than hearing aid amplification (aOR 2.02, 95% CI 1.05-3.89, p=0.036).

Comorbidity, laterality, and device type

Enrollment in early-intervention services within 60 days of diagnosis was independently associated with improvement (aOR 2.71, 95% CI 1.49-4.93, p=0.001), and absence of a comorbid developmental disability was independently associated with improvement (aOR 2.14, 95% CI 1.12-4.08, p=0.021). Genetic etiology, degree of hearing loss category, sex, maternal education, and

household language concordance were not independently associated with the outcome after adjustment (all p>0.10). The full multivariable model, summarized in Table 2, showed acceptable discrimination (area under the receiver operating characteristic curve 0.76).

Table 2: Independent predictors of clinically meaningful 12-month symptom score improvement, multivariable logistic regression (n=214).		
Predictor	Adjusted OR (95% CI)	p-value
Intervention age <12 months (ref: >36 months)	3.42 (1.86-6.29)	<0.001
Intervention age 12-36 months (ref: >36 months)	1.61 (0.89-2.92)	0.11
Bilateral device fitting (ref: unilateral)	2.28 (1.24-4.19)	0.008
Early-intervention enrollment <=60 days	2.71 (1.49-4.93)	0.001
No comorbid developmental disability	2.14 (1.12-4.08)	0.021
Cochlear implantation vs hearing aid (severe-profound)	2.02 (1.05-3.89)	0.036

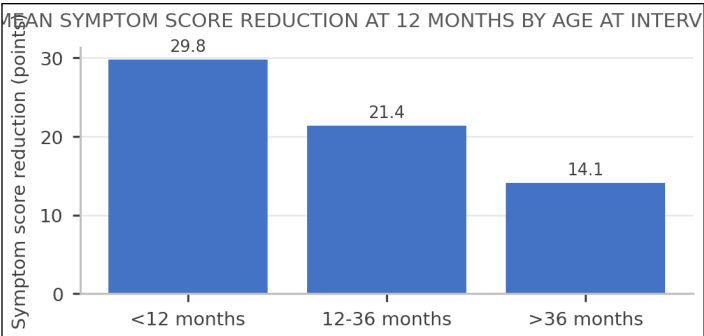


Figure 1: Mean 12-month symptom score reduction by age at intervention initiation, largest among children intervened before 12 months of age and smallest among those intervened after 36 months, consistent with the early-intervention timing literature [8,9].

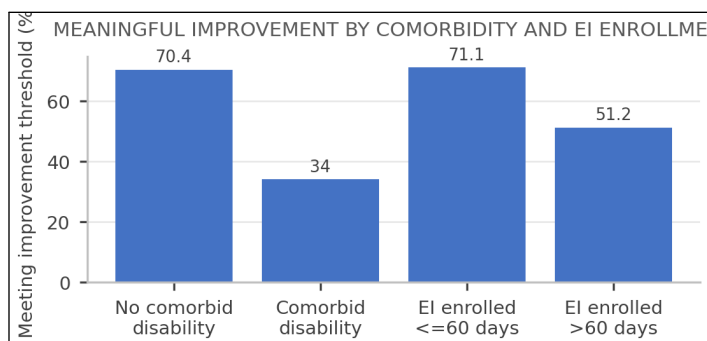


Figure 2: Proportion of children meeting the clinically meaningful symptom improvement threshold (≥ 15 -point reduction) by comorbid developmental disability status and by early-intervention enrollment timeliness [15,18].

4. Discussion

In this multicenter retrospective cohort, roughly two-thirds of children with sensorineural hearing loss achieved a clinically meaningful reduction in composite symptom score within 12 months of diagnosis, and the strongest independent predictors were early intervention timing, bilateral device access, prompt early-intervention enrollment, and absence of a comorbid developmental disability. These findings extend a well-established language-outcomes literature into a shorter, more clinic-relevant time horizon than the standardized speech and language test batteries typically used in cochlear implant outcome research.

The association between earlier intervention and greater symptom improvement is consistent with prior work. Yoshinaga-Itano and colleagues first demonstrated that children enrolled in intervention before 6 months of age had significantly better language outcomes than later-identified peers, establishing the conceptual basis for universal newborn hearing screening [3]. The LOCHI study subsequently quantified this relationship prospectively, showing that each additional month of delay before intervention was associated with measurably poorer language outcomes at age 3, an effect that persisted, though attenuated, at 5 years [7,8]. Our finding that intervention before 12 months conferred more than three-fold higher odds of symptom improvement than

intervention after 36 months is broadly consistent with that literature, and reinforces that the sensitive period for auditory development narrows across the second and third years of life [20,21]. Harrison and colleagues similarly described a graded rather than sharply bounded critical period, while Holt and Svirsky cautioned against assuming earliest implantation is uniformly optimal once comorbid factors are considered, consistent with our finding that comorbidity attenuated the benefit of early intervention here [22,23]. Ching's broader appraisal of the evidence base likewise concluded that timing effects interact with etiology, severity, and family factors in ways a single threshold cannot fully capture [24].

The advantage of bilateral device fitting mirrors findings from Boons and colleagues, who reported faster language development with bilateral than unilateral cochlear implants [11], and is consistent with evidence that unilateral or asymmetric hearing loss is independently associated with worse speech-language outcomes than symmetric bilateral loss of comparable severity [12,13,25]. The relative advantage of cochlear implantation over hearing aids among children with severe-to-profound loss is also consistent with the CDaCI study, in which implanted children showed steeper spoken-language growth than expected under amplification alone [9,26]. Nicholas and Geers similarly found that earlier, more consistent auditory experience predicted better spoken-language outcomes at age 3, reinforcing the interaction between device type, severity, and timing our model also captured [27].

The independent association between prompt early-intervention enrollment and symptom improvement echoes a long-standing emphasis on family-centered early intervention as a parallel track to audiologic management [18,28]. Wake and colleagues, in a population-based Australian cohort, similarly found that coordinated early support services alongside amplification produced better functional outcomes at

school age than audiologic intervention alone [29], and our results suggest this benefit is detectable within a single year.

Consistent with prior work on cochlear implantation outcomes in children with additional disabilities, comorbid developmental disability was associated with substantially lower odds of meeting the improvement threshold here [15,14]. This does not imply intervention is less valuable in this subgroup; rather, symptom trajectories in children with additional disabilities may require longer follow-up or different outcome thresholds than the 12-month, 15-point benchmark used here, consistent with systematic review evidence that children with hearing impairment and comorbid conditions show more heterogeneous developmental trajectories [30]. Degree of hearing loss and etiology were not independently predictive after adjustment for timing and device type, suggesting that once access to appropriately timed, lateralized intervention is accounted for, baseline audiologic severity contributes less additional predictive information for this short-term outcome than for longer-horizon language scores.

Several limitations warrant consideration. The retrospective, multicenter design introduces potential confounding by indication, since children referred earlier or judged appropriate for bilateral devices may differ systematically from those who are not, and unmeasured socioeconomic and family-engagement factors likely contribute to both intervention timing and symptom trajectory [31]. The composite symptom score, while structurally consistent with validated pediatric hearing-related instruments, was not independently re-validated in this cohort, and the 15-point threshold has not been formally anchored to family-reported meaningfulness. Finally, the 12-month horizon cannot capture the longer-term trajectories over which some of the strongest cochlear implantation outcome differences have been shown to emerge [32,33].

5. Conclusion

In this multicenter cohort of children with sensorineural hearing loss, intervention before 12 months of age, bilateral device fitting, prompt early-intervention enrollment, and absence of comorbid developmental disability were each independent predictors of clinically meaningful symptom score improvement within the first year after diagnosis. These findings extend, to a shorter and more clinic-relevant time horizon, the established relationship between early, appropriately lateralized intervention and favorable communication outcomes in pediatric SNHL, supporting continued emphasis on minimizing the interval between diagnosis and both audiologic and early-intervention service enrollment, while highlighting the need for tailored outcome expectations in children with more complex developmental profiles.

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