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Unilateral hearing loss in children: speech-language and school performance

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Abstract. *Unilateral hearing loss in children: speech-language and school performance. Problem/Objectives*: Unilateral hearing loss (UHL) in children is a relatively common problem often identified by newborn screening or school screening. This review summarizes the outcomes of a large study of children with UHL which identified risk factors for educational problems, describes the results of pilot studies of intervention, and proposes guidelines for interventions and future studies.

Methods: Cohort of children age 6-12 years with UHL was compared to their siblings with normal hearing on the primary outcomes of cognition, achievement, and language. Secondary outcomes examined included behavioral, speech, and educational problems. A subgroup of children with UHL was followed longitudinally to examine change over time.

Results: Children with UHL had lower language and verbal IQ scores than their siblings with normal hearing. They required individualized education plans (a measure of educational difficulty) at three times the rate and speech therapy at twice the rate of their siblings. The additional educational concerns did not ameliorate over time. Low maternal education levels and lower baseline cognitive skills were independent risk factors for school problems. Pilot studies suggest that children with UHL might benefit from amplification, but may need attention to cognitive or executive function skills as well.

Conclusions: Children with UHL are at risk for delays in speech-language development, cognition, and behavioral problems that can affect functioning at school. Controlled studies are urgently needed to determine whether amplification, auditory rehabilitation, school-provided educational assistance, or other interventions are able to reduce or eliminate this risk.

Introduction

Unilateral hearing loss (UHL) causes two well-known problems associated with the lack of binaural hearing: difficulty with speech perception in background noise and sound localization. Adults with UHL frequently complain of diminished quality of life or hearing handicap and may choose to use hearing aids or Baha to help overcome this handicap.[1,2] In children with UHL, the conventional advice to parents was to make sure that they sat at the front of the classroom, and that speech and language would develop normally. However, in the 1980s and 1990s, articles from the United States reported that 24-35% of children with UHL failed grades compared to a 3% rate of grade failures in the remainder of the population, and that 22-59% received additional educational assistance.[3] Although an increasing number of audiologists and otolaryngologists acknowledge the difficulties that children with UHL experience, UHL is not universally considered a “significant hearing loss”; children with UHL are not eligible to receive services or accommodations for hearing disability some states in the United States, and countries such as the United Kingdom define permanent hearing loss in children as bilateral hearing loss ≥40 dB.[4,5,6,7]

Unilateral congenital hearing loss is diagnosed in about 1 per 1000 infants through newborn hearing screening programs, or approximately one-third of all infants with congenital hearing loss.[8,9] As they grow older, more children are diagnosed with UHL, whether due to delayed-onset congenital hearing loss or acquired etiologies such as infection, trauma, or ototoxic exposures (including noise). In the United States, 19.5% of adolescents have a hearing loss of at least 15 dB in at least one ear, and 2.5% have a hearing loss of at least 25 dB.[10]

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Speech-language effects

Few investigators have studied the effect of UHL on acquisition of speech and language skills in infants and toddlers. Kiese-Himmel asked parents when their children with UHL (n = 31) spoke their first word and first two-word phrase and found that the average age of the first word spoken was 12.7 months (range 10 to 33 months) and the average age of the first two-word phrase was 23.5 months (range 18 to 48 months).[11] Although the age of the first word spoken was not delayed, the age at the first two-word phrase was delayed an average of 5 months, based on a norm of 18 months. The Colorado Home Intervention Program followed 15 children with UHL identified as infants and assessed speech and language skills when the children were at least 12 months of age (Sedey, Carpenter, Stredler-Brown. Unilateral hearing loss: what do we know, what should we do? Presented at: National Symposium on Hearing in Infants; August 1, 2002; Breckenridge CO). The children did not have any other known disabilities, but 4 (27%) had significant language delays, and 1 (7%) had a borderline language delay.

Early studies investigating language skills in preschool or school-aged children have shown mixed results. A study of 44 7-year-old children with severe UHL found that at 11 years of age, only four still had poor speech intelligibility and had similar reading scores to NH peers.[12] However, at least 13 of the 44 children had temporary hearing loss. In 25 6-to-13-year-old children with UHL, Klee and Davis-Dansky found few differences from controls with NH (matched on age, intelligence quotient [IQ], socioeconomic status, sex, and race) on a battery of six standardized language tests.[13] In contrast, Borg and colleagues found that 4- and 5-year old children with UHL had delayed language development compared with their peers with NH.[14] The investigators did not find differences between children with right- or left-ear UHL. Cozad compared 18 children and young adults (age 8 to 20 years) with severe to profound UHL with NH peers on standardized tests of vocabulary.[15] No statistically significant differences were reported.

School performance effects

A systematic review of the literature showed that school-aged children with UHL had high rates of repeating a grade (22-35% compared with baseline rates of 3%) and receiving additional educational assistance (12-41%).[3] The state of Colorado reported a 36% rate of Individualized Educational Plans (IEPs), a measure of school-recognized educational difficulty, among children with UHL Teachers tended to report that children with UHL had lower academic performance than children with NH, using a screening teacher-based assessment called Screening Instrument For Targeting Educational Risk (SIFTER). In addition, remarks about qualitative behavioral problems were common. Other investigators have suggested that children with right-sided UHL had more problems with verbal tests (including IQ), and that profound UHL seemed to be associated with decreased IQ.

The pathophysiologic mechanisms through which UHL affects speech-language development and school performance remain uncertain, but may be related to impaired binaural summation and sound localization. Loss of binaural summation may decrease incidental learning because background noise interferes with overheard speech. Severity of UHL may affect the quality and quantity of the auditory signal from the impaired ear and thus conceivably impair speech-language development on a graduated scale. Children with difficulty localizing sound may expend effort to locate the sound rather than to comprehend the spoken language. Based on theories of a "right ear advantage" for language learning, right-sided UHL has been thought to be associated with greater disadvantage compared to left-sided UHL.

The purpose of this review is to summarize the outcomes of a large observational controlled study of children with UHL which was intended to identify risk factors for educational problems, describe the results of pilot studies of intervention, and to propose guidelines for interventions and future studies.

Materials and methods

Institutional Review Board approval was obtained prior to the onset of these studies. All parent and child participants signed written informed consents and pediatric assents, respectively.

Study design

We conducted a case-control study of children aged 6-12 years old with permanent UHL compared with siblings with normal hearing (NH). A subset of children with UHL was followed longitudinally over 3 years. UHL was defined as an average threshold of any three consecutive frequencies of ≥30 dB hearing level (HL) in the affected ear. NH in the other ear was defined as a pure tone threshold average (PTA) of 500, 1000, and 2000 Hz of <20 dB HL, and threshold at 4000 Hz <30 dB. Permanent UHL was operationally defined as sensorineural or mixed/conductive hearing loss that was reversible with any known medical or surgical therapy during the course of the study. Children were excluded if they had temporary or fluctuating conductive UHL, or had a medical diagnosis associated with cognitive impairment (e.g., Down syndrome, congenital cytomegalovirus infection) or cognitive impairment per parental report.

Demographic and baseline clinical variables

Participant demographic information, parental socioeconomic data, current and past medical history of participants, and educational history of participants were obtained through parental questionnaire and interview. Income level was determined by calculating the percentage of federal poverty level (FPL), based on family size and household income, as defined by the US Department of Health and Human Services.[16] Each child underwent a brief otolaryngologic examination, and occluding cerumen was removed before audiologic measures were obtained in a double-walled soundproof booth. Severity of UHL was categorized as: mild = PTA <40 dB HL; moderate = PTA 40 to 69 dB HL; severe = PTA 70 to 89 dB HL; and profound = PTA ≥90 dB HL. Word recognition scores (WRS) using CID W-22 word lists were obtained in quiet and in noise. WRS in quiet were obtained monaurally through headphones at 40 dB sensation level (SL) relative to their PTA or at the participant's most comfortable loudness level (MCL) if recruitment became a problem. WRS in noise were obtained at +5 and 0 dB signal-to-noise ratios (SNR) in the soundfield with 8-talker speech babble. Words were presented through a speaker at 0 degrees azimuth, with two speakers presenting the noise at 30 degrees from midline on each side of the participant.

Outcome measures

Cognitive ability was measured using the Wechsler Abbreviated Scale of Intelligence (WASI), which provides Verbal, Performance, and Full scale IQ scores. Achievement was measured using the Wechsler Individual Achievement Test-Second Edition-Abbreviated (WIAT-II-A) that includes standardized scores for reading, math, and writing. Oral language skills were measured with the Oral Written and Language Scales (OWLS) using the subtests of Listening comprehension, Oral Expression, and Oral Composite. All scores were standardized for age, with a mean of 100 and standard deviation (SD) of 15.

Behavioral problems were measured using the Child Behavior Checklist (CBCL), completed by the parent or caregiver.[17]

Statistical analysis

Descriptive statistics were obtained for each group, and included means and standard deviations, medians and interquartile ranges, and frequency counts. Bivariate analyses examined the outcomes associated with patient demographic, baseline clinical, and audiologic variables. Student's t test or one-way ANOVA were used for continuous variables. Correlations were tested with the Pearson *r* test. Chi-square or Fisher exact tests were used for categorical variables. Bivariate analysis of other outcomes involved calculating the odds ratio (OR) and 95% confidence interval (CI). Multivariable linear regression was used to determine independent predictors of outcomes for the overall case-control study. Random effects multilevel modeling was used for the longitudinal study. A two-tailed alpha level of 0.05 was considered statistically significant. Statistical analysis was performed using SAS version 9.2 software (Cary, North Carolina).

Results

The entire study recruited 109 children with UHL and 95 sibling controls with NH; a subset of 46 children with UHL was followed longitudinally over 3 years. Demographic and selected clinical characteristics of the participants are shown in Table 1. Children with UHL were slightly younger than their siblings with NH, spoke their first two-word phrase later, and had suffered more head trauma. Race and ethnic distribution approximated the metropolitan distribution: 76% white, 16% black, 6% Hispanic or Latino, 4% Asian, 3% mixed or not stated, and 0.5% American-Indian. Overall level of

Table 1

Demographic and clinical characteristics of 109 children with unilateral hearing loss (UHL) compared to 95 siblings with normal hearing (controls)

	UHL	Controls	*P* value
Age, mean years (SD)	8.62 (1.87)	9.25 (2.40)	0.04
Males, n (%)	53 (48.6%)	48 (50.5%)	0.89
Adopted, n (%)	10 (9.17%)	7 (7.37%)	0.60
First-born, n (%)	44 (40.4%)	35 (36.8%)	0.78
Mean birth weight, grams (SD)	3226 (646)	3331 (687)	0.27
Premature, n (%)	13 (11.9%)	11 (11.6%)	0.89
Birth complication, n (%)	24 (22.0%)	17 (17.9%)	0.49
Age at 1st word, mean months (SD)	11.1 (4.18)	9.99 (4.27)	0.07
Age at 1st 2-word sentence, mean months (SD)	18.5 (8.90)	15.4 (7.94)	0.02
Head trauma, n (%)	17 (15.6%)	3 (3.16%)	0.008
Chronic medical problems			
Asthma, n (%)	23 (21.1%)	13 (13.7%)	0.20
Recurrent otitis media, n (%)	31 (28.4%)	20 (21.1%)	0.26
ADHD, n (%)	14 (12.8%)	6 (6.3%)	0.16
Takes regular meds, n (%)	49 (45.0%)	36 (37.9%)	0.32
Right handed, n (%)	90 (82.6%)	82 (86.3%)	0.70
Wears glasses, n (%)	27 (24.8%)	26 (27.4%)	0.75

maternal education was high; 44% of mothers had completed a bachelor's degree or higher, 35% had enrolled in some college or achieved an associate's degree, and 13% had graduated from high school or achieved a General Educational Development certificate. Only 7% of mothers had not completed high school. The majority (75.9%) came from families with incomes >200% of the federal poverty level (FPL), 9.4% were from families with incomes at 100-200% FPL, and 14.8% came from families <100% of FPL.

Most of the children with UHL in this study had severe (18%) or profound (57%) UHL and slightly more right ears than the left ears were affected. UHL was identified at a mean age of 4.6 years (SD 2.6 years); the mean duration of known hearing loss was 4.0 years (SD 2.7 years). Thirty children (27%) had ever used an FM system, 18 had ever tried a hearing aid, and 4 each had tried a CROS aid or bone-anchored hearing aid. The etiology of UHL was congenital or hereditary in about one-third; this included enlarged or prominent vestibular aqueduct in 15 (20%), seven (10%) with a cochlear malformations, four (5%) with an ossicular abnormality, and three (4%) with atresia. Acquired etiologies included seven (6%) with temporal bone fractures and three (4%) with a history of meningitis. For many (47%), etiology remained unknown.

Standardized cognition, achievement, and language scores

Table 2 summarizes the cognitive, achievement, and oral language scores for children with UHL compared to their siblings with NH. Children with UHL had lower Verbal and Full Scale IQ scores than children with NH. There were no significant differences in reading, math, or writing achievement scores between groups. However, all the oral language scores were significantly lower for children with UHL. When the children with right-sided and left-sided UHL were compared to each other, there were no differences in cognitive, achievement, or language scores (data not shown).

Because socioeconomic and other individual factors can influence cognitive and language scores, multiple linear regression models were evaluated to identify the most important predictors of these scores. Table 3 shows that UHL was associated with a persistent 2.8 to 4.5 point decrease in IQ scores, whereas increasing maternal educational level was associated with 4.5 to 6.3 point increase

Table 2

Standardized scores on cognitive, achievement, and oral language tests in 104 children with unilateral hearing loss (UHL) compared with 91 siblings with normal hearing (NH). Standard scores range from 40 to 160 by age and grade, with mean = 100 and SD = 15

Outcome scores	**UHL Mean (SD)**	**NH Mean (SD)**	**P value**
Cognitive			
Verbal sum IQ	100.9 (16.3)	105.5 (14.6)	0.040
Performance sum IQ	99.8 (14.4)	102.6 (14.5)	0.168
Full scale IQ	100.5 (15.2)	104.5 (14.3)	0.052
Achievement			
Reading	101.1 (15.3)	102.7 (15.4)	0.470
Math	96.6 (15.9)	99.2 (16.6)	0.251
Writing	101.5 (14.8)	103.5 (16.2)	0.368
Oral language			
Listening comprehension	91.7 (10.9)	96.7 (14.2)	0.007
Oral expression	92.7 (15.8)	100.1 (18.5)	0.003
Oral composite	90.6 (13.0)	98.0 (15.7)	0.0004

Table 3

Multivariable regression model of verbal, performance and full IQ scores

Variables	**Parameter estimate**	**SE**	**t value**	**P value**
Verbal IQ				
Intercept	85.33	3.87	22.05	<.0001
UHL	-4.51	2.04	-2.21	.028
Maternal education level	6.33	1.12	5.64	<.0001
Performance IQ				
Intercept	89.10	3.75	23.77	<.0001
UHL	-2.82	1.98	-1.42	.1561
Maternal education level	4.45	1.09	3.90	.0001
Full IQ				
Intercept	85.79	3.70	23.22	<.0001
UHL	-4.06	1.95	-2.08	.0384
Maternal education level	5.89	1.07	5.50	<.0001

in IQ scores. Table 4 shows that in addition to UHL and maternal educational level, age and baseline cognitive ability were also associated with language scores.

School performance and behavior

Although there were no differences in repeated grades or grade failures (7% for UHL, 5% for NH) parents reported higher rates of IEPs among children with UHL (41% vs. 14%, $p < 0.001$) and history of receiving speech therapy (41% vs. 22%, $p = 0.006$). Comparisons on the CBCL questionnaire shows that children with UHL appeared to have more problems with school competency (4.59 [SD 1.22] for UHL vs. 4.09 [1.16] for NH, $p = 0.003$), attention (4.87[SD 4.44] for UHL vs. 3.16 [SD 3.93] for NH, $p = 0.004$) and ADHD-type problems (4.31 [SD 3.50] for UHL vs. 2.86 [SD 3.36] for NH, $p = 0.003$) than their siblings with NH.

Nested longitudinal cohort study[18]

A subset of 46 children was prospectively followed over the course of three years to determine whether language skills and educational performance

Table 4
Multivariable regression models of oral language scores

Variables	Parameter estimate	SE	t value	P value
Listening comprehension				
Intercept	45.53	6.79	6.70	<.0001
UHL	-2.97	1.59	-1.87	.0632
Full IQ	0.43	0.057	7.57	<.0001
Age	0.62	0.37	1.68	.0948
Maternal education level	0.036	0.92	0.04	.9685
Oral expression				
Intercept	-3.07	7.33	-0.42	.6758
UHL	-3.60	1.71	-2.10	.0370
Full IQ	0.75	0.062	12.11	<.0001
Age	1.63	0.40	4.08	<.0001
Maternal education level	3.16	0.99	3.19	.0017
Oral composite				
Intercept	19.67	6.73	2.92	.0039
UHL	-4.39	1.57	-2.79	.0059
Full IQ	0.59	0.056	10.38	<.0001
Age	1.24	0.36	3.40	.0008
Maternal education level	1.72	0.91	1.89	.0605

improved or worsened over time. Verbal and full IQ, and Oral Expression and Oral Composite scores increased significantly over time (Table 5). Possible predictors of increase with time included higher cognitive levels at baseline and receipt of interventions through an IEP. Nevertheless, indicators of school performance, including rates of IEPs (approximately 50%), speech therapy and academic difficulty (each about 20-25%) noted by teachers, did not show improvements. These indicators suggest that children with UHL are prone to persistent delays in academic development compared to children with NH.

Discussion

Although delays in language, reading, and academic achievement in children with bilateral hearing loss are well-recognized and are the impetus for newborn hearing screening programs across the globe, the possibility that children with UHL might have similar problems has been slower in recognition and acceptance. Why UHL would result in language delay and educational problems is not yet well understood, but are thought to stem from the impaired binaural ability to understand speech-in-noise and localize sound. The ability to learn overheard conversation, so-called incidental learning, may thus be diminished. Innate cognitive ability, severity of UHL, and socioeconomic status appear to be modifying factors that can exacerbate or mitigate the problems associated with UHL.

Speculatively, other mechanisms may underlie the increased risk for speech-language and education problems in children with UHL. Anecdotal reports of increased behavioral problems at school are supported by our findings of increased problems with attention and school competency as reported by the parents of our study population. Brain network interconnections appear to differ in children with UHL as compared to those with NH, in areas that have been associated with auditory processing, executive function, and memory formation.[19] Preliminary data from ongoing studies from our research group suggest that phonological processing is affected by UHL, and we theorize that verbal working memory might be slowed as well.

Children with UHL become aware of their unilateral hearing deficit as they enter school and experience diminished hearing-related QOL compared

Table 5

Random regression (multilevel) models of the effect of time, defined as age at testing beginning at 6 years old, in 46 children with unilateral hearing loss.

Outcome	**Initial Status (SE)**	**Rate of Change (SE)**	**Pseudo R^2**
Full IQ	97.5 (2.7)***	1.76 (0.59)**	0.109
Verbal IQ	96.1 (2.9)***	2.48 (0.76)**	0.115
Performance IQ	100.0 (2.7)***	0.34 (0.61)	0.017
Reading achievement	104.3 (2.4)***	-0.24 (0.52)	0
Math achievement	93.8 (2.8)***	0.50 (0.72)	0
Writing achievement	99.8 (3.4)***	1.44 (0.93)	0.026
Listening comprehension	90.6 (2.4)***	1.04 (0.69)	0.045
Oral expression	85.5 (2.8)***	2.87 (0.70)***	0.149
Oral composite	85.3 (2.7)***	2.48 (0.72)**	0.168

Note: The Initial Status provides the model's calculated mean baseline score at the age of 6 years. The Rate of Change indicates the slope of the change in scores over time (i.e., calculated change in score per year). The Pseudo R^2 values provide the proportional within-person variance that is explained by the effect of time.
*p<0.05, **p<0.01, ***p<0.001.

to children with NH.[20] The magnitude of their perceived difficulty is similar to children with bilateral hearing loss (Rachakonda, Jeffe, Shin, *et al*. Validity, Discriminative Ability and Reliability of the Hearing-Related Quality of Life (HEAR-QL) Questionnaire for Adolescents, personal communication).[21] Interestingly, children with UHL who use a hearing device, such as a hearing aid, tend to report lower QOL scores than those who do not use a device, despite a pilot study that showed large subjective improvements in hearing function.[22]

Intervention Studies for Hearing Rehabilitation

Traditionally, parents were advised to ensure that their children with UHL should sit in the front of the classroom with either better-hearing ear facing the teacher. If possible, schools should provide frequency-modulated (FM) devices to place on the desks of these students. This was based on studies showing that FM systems improved word recognition scores in quiet and noise of children with UHL.[23,24] In contrast, it was thought that conventional analog hearing aids or contralateral routing of signal (CROS) aids did not improve speech understanding and instead interfered with speech perception in noise.

More contemporary studies of conventional digital hearing aids in children with UHL have shown that although there was no significant benefit in quiet or noise speech perception, there was also no detriment. Instead, children and parents reported large subjective improvements.[22] Others have found mixed results with the use of conventional hearing aids in terms of sound localization; older children with hearing aids performed worse, but younger children with hearing aids had better sound localization.[25]

Another option for noninvasive rehabilitation of UHL includes the TransEar, a bone-conduction device that uses transcranial contralateral routing of signal. To date, one study in adults with profound UHL has shown that sound localization is not significantly improved, similar to results with the BAHA, even though reduction of the head shadow effect and improvement of signal-to-noise ratios are reported subjectively.[26]

For children with severe-to-profound UHL that is not amenable to conventional hearing aids, the use of a bone-anchored hearing aid (BAHA) is gaining increasing acceptance. In adults with UHL, using a BAHA has been shown to reduce the head shadow effect, resulting in subjective improvement with ease of conversation and in reverberant conditions.[27,28] However, others have found that sound localization in horizontal plane is no better with the use of a BAHA, and may be worse.[29,30] Similarly, 23 children with UHL (age 6-19 years) had improved speech-in-noise and satisfaction scores using the BAHA as compared to before its placement.[31] One study found that those with high-frequency UHL or who experience more problems in listening were more likely to accept implantation after a softband trial.[32] Thus, they recommended that patient undergo at least a one-week trial of a softband BAHA before making their decision about an eventual implant.

Cochlear implantation is the next frontier of investigation in the treatment of UHL. Case series in adults have found improvements with word recognition in noise, sound localization, and subjective perception of hearing.[33,34] Hassepass *et al*.[35] reported cochlear implantation in 3 children (ages 4, 10, and 11 years) with acquired profound UHL. They reported binaural hearing benefits for speech in noise, localization ability, and subjective hearing ability, similar to reports in adults. What remains to be shown is whether cochlear implantation is able to eliminate the risks of speech delay and educational problems, making the invasiveness of this procedure worth recommending to a broader population of children with profound UHL.

Conclusions

Children with UHL are at risk for delayed speech-language development, behavioral problems in school, experiencing educational difficulties, and needing additional educational help in schools. Further studies are needed to understand the pathophysiologic mechanisms and associated factors underlying this increased risk. Controlled studies are urgently needed to determine whether amplification, auditory rehabilitation, school-provided educational assistance, or other interventions are able to reduce or eliminate this risk in children with UHL.

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