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Neurocognitive Risk in Children With Cochlear Implants

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Abstract

IMPORTANCE—Children who receive a cochlear implant (CI) for early severe to profound sensorineural hearing loss may achieve age-appropriate spoken language skills not possible before implantation. Despite these advances, reduced access to auditory experience may have downstream effects on fundamental neurocognitive processes for some children with CIs.

OBJECTIVE—To determine the relative risk (RR) of clinically significant executive functioning deficits in children with CIs compared with children with normal hearing (NH).

DESIGN, SETTING, AND PARTICIPANTS—In this prospective, cross-sectional study, 73 children at a hospital-based clinic who received their CIs before 7 years of age and 78 children with NH, with average to above average mean nonverbal IQ scores, were recruited in 2 age groups: preschool age (age range, 3–5 years) and school age (age range, 7–17 years). No children presented with other developmental, cognitive, or neurologic diagnoses.

INTERVENTIONS—Parent-reported checklist measures of executive functioning were completed during psychological testing sessions.

MAIN OUTCOMES AND MEASURES—Estimates of the RR of clinically significant deficits in executive functioning (≥ 1 SDs above the mean) for children with CIs compared with children with NH were obtained based on 2 parent-reported child behavior checklists of everyday problems with executive functioning.

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Study concept and design: Kronenberger, Beer, Pisoni, Miyamoto.
Acquisition, analysis, or interpretation of data: All authors.
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RESULTS—In most domains of executive functioning, children with CIs were at 2 to 5 times greater risk of clinically significant deficits compared with children with NH. The RRs for preschoolers and school-aged children, respectively, were greatest in the areas of comprehension and conceptual learning (RR [95% CI], 3.56 [1.71–7.43] and 6.25 [2.64–14.77]), factual memory (4.88 [1.58–15.07] and 5.47 [2.03–14.77]), attention (3.38 [1.03–11.04] and 3.13 [1.56–6.26]), sequential processing (11.25 [1.55–81.54] and 2.44 [1.24–4.76]), working memory (4.13 [1.30–13.06] and 3.64 [1.61–8.25] for one checklist and 1.77 [0.82–3.83] and 2.78 [1.18–6.51] for another checklist), and novel problem-solving (3.93 [1.50–10.34] and 3.13 [1.46–6.67]). No difference between the CI and NH samples was found for visual-spatial organization (2.63 [0.76–9.03] and 1.04 [0.45–2.40] on one checklist and 2.86 [0.98–8.39] for school-aged children on the other checklist).

CONCLUSIONS AND RELEVANCE—A large proportion of children with CIs are at risk for clinically significant deficits across multiple domains of executive functioning, a rate averaging 2 to 5 times that of children with NH for most domains. Screening for risk of executive functioning deficits should be a routine part of the clinical evaluation of all children with deafness and CIs.

Permanent hearing loss is a common condition of early childhood, with a prevalence of approximately 1.5 in 1000 births.[1] Early detection, intervention, and monitoring of children with hearing loss are recommended to promote optimal communication, language, socioemotional, cognitive, and motor development skills.[2] For infants and children with severe to profound deafness who receive limited benefit from hearing aids, cochlear implantation provides access to acoustic cues in the environment that can support the development of spoken language skills. Although many children who use cochlear implants (CIs) are able to achieve spoken language skills that were not possible before implantation,[3,4] most of these children continue to be at risk for significant difficulties in reading and writing skills[5] and speech perception deficits in adverse listening environments.[6] Furthermore, recent studies provide evidence of additional risks in domain-general neurocognitive processes that are dependent, in part, on typical auditory, speech, and language experience, including sequential processing,[7] working memory,[8] and executive functioning (EF).[9]

Because early cortical development is driven by experience-dependent factors, including auditory stimulation, the central auditory pathways of children with congenital deafness are organized in fundamentally different ways from children with normal hearing (NH).[10,11] Neuroimaging and neurocognitive studies[12,13] further suggest that the development of cognitive domains and brain regions associated with controlled attention and working memory is affected by auditory and linguistic experience. Hence, the functional risks associated with auditory deprivation extend beyond hearing and spoken language skills and encompass other domains of neurocognitive development.[14]

Executive functioning skills appear to be particularly vulnerable to the effects of auditory deprivation because they rely heavily on fundamental elementary processes, such as sequential processing, mental fluency and efficiency, and robustness of representations, which are highly dependent on auditory and phonologic or lexical experience for development.[7,12] Although there is no universally accepted definition of EF, we adopted a

broad view of EF as skills necessary to organize, control, and sustain the processing of information in a planned, goal-directed manner. In this view, EF encompasses a set of diverse but related abilities, including concept formation, working memory, controlled attention, novel problem solving, sustained sequential processing (ie, planning), organization, and mental efficiency and speed.[12,15,16]

Because EF is critically important for social, learning, and behavioral success, deficits in these skills can have a significant effect on functional quality of life.[9,17–22] Furthermore, evidence of the effectiveness of targeted interventions to improve EF skills is mounting.[23–26] Hence, it is important to identify conditions associated with EF risk to promote early assessment and targeted intervention.

Research to date on EF skills of children after cochlear implantation has primarily used clinic-based, neurocognitive measures. Although these types of assessments provide important diagnostic information about fundamental processing abilities, they correspond only modestly to EF skills in real-world, day-to-day settings,[27] require highly trained clinicians for administration and interpretation, and are lengthy and costly to obtain. Parent-reported behavior checklists are increasingly used as an alternative, less costly, more ecologically valid method of measuring daily EF behaviors.[16,27] Preliminary studies[28] using parent-reported behavior checklists suggest elevated risks of EF delays in small pilot samples of children with CIs. Given the increasing use of cochlear implantation in profoundly deaf children and the potential risk of EF delays in this population, a pressing need exists to better understand the type and magnitude of EF deficits in day-to-day behaviors of children with CIs. This need is further accentuated by the fact that EF deficits are currently not routinely screened in basic clinical assessments of children with CIs.

We sought to address this need by investigating parent-reported EF behavior in children with CIs compared with peers with NH during 2 developmental periods: preschool age and school age. Our objectives were (1) to identify real-world EF behaviors that are delayed in children with CIs relative to children with NH and (2) to determine the relative risk of clinically significant EF deficits in children with CIs compared with children with NH.

Methods

Participants

The study procedures were approved by the Indiana University Institutional Review Board. Written consent was provided by parents of all participants (with written assent by older children, as appropriate). The study used a cross-sectional design to compare 73 children with CIs with 78 children with NH in 2 age groups, preschool age (age range, 3–5 years) and school age (age range, 7–17 years), using 2 well-validated parent-reported EF behavior checklists. Eligibility criteria for children with CIs included (1) severe to profound bilateral hearing loss (>70-dB hearing loss in the better hearing ear) before 4 years of age, (2) cochlear implantation before 7 years of age, and (3) current or prior enrollment in a rehabilitative or educational program emphasizing spoken language development. Eligibility criteria for children with NH included hearing within normal limits based on ear-specific pure-tone audiometric screening at 20 dB. Eligibility criteria for both groups included (1)

absence of any developmental, cognitive, or neurologic diagnoses and (2) monolingual English home environment.

Children with CIs were recruited from a large hospital-based clinic and from advertisements in the local community; children with NH were recruited through advertisements posted in the same locations. Of the 56 preschool-aged children who originally consented to the study, 1 child with NH was excluded because of refusal to cooperate with the hearing examination, 2 children with CIs were excluded because of additional developmental diagnoses, and 2 children (1 with a CI and 1 with NH) were excluded because their parents did not complete either of the behavioral rating checklists used in the study. The resulting 51 preschool-aged children (24 with CIs and 27 with NH) were included in the final study sample. All 100 school-aged children who were tested (49 with CIs and 51 with NH) and met the entry criteria were included in the study. One preschool-aged child in the CI sample had missing data for nonverbal IQ because of an inability to complete the test but was retained for the study sample based on examiner judgment that no severe deficit in intelligence was present. Parents of 2 school-aged children (1 with a CI and 1 with NH) failed to complete one behavior checklist.

No differences were found in chronologic age, family income, or sex between the CI and NH groups (Table 1).[29] However, preschool-aged children with NH scored higher on nonverbal IQ tests (Differential Ability Scale II picture similarities subtest)[30] than preschool-aged children with CIs ($t_{48} = -2.121$, $P = .04$). No differences were found in nonverbal IQ test results (Wechsler Abbreviated Scale of Intelligence matrix reasoning subtest)[31] in the school-aged subsamples.

Procedure

Data were obtained from 2 studies (a longitudinal preschool-aged study and a cross-sectional school-aged study) of neurocognitive and spoken language development in children with CIs. While the child completed other testing, parents completed checklists to assess their child's everyday behavior in the home environment. Only data from the parent-reported EF behavior checklists were analyzed for this study.

Measures

Executive functioning was assessed using 2 parent-reported behavior checklists: the Learning, Executive, and Attention Functioning Scale (LEAF)[32] and the Behavior Rating Inventory of Executive Function (BRIEF; either the school-age[16] or preschool-age[33] version). LEAF is a 55-item rating scale of child behavior in the past week. LEAF yields 8 EF-related subscale scores: (1) comprehension and conceptual learning, (2) factual memory, (3) attention, (4) processing speed, (5) visual-spatial organization, (6) sustained sequential processing, (7) working memory, and (8) novel problem solving. In prior research, LEAF scores have demonstrated strong internal consistency, test-retest reliability, and validity as measures of EF, including significant correlations with scores on other EF behavior checklists and neurocognitive measures of EF.[32] Because LEAF does not have norms, T scores for LEAF sub-scales were derived for each participant using the raw score means and SDs from the NH preschool- and school-aged sub-samples in this study.

BRIEF is a parent-reported questionnaire of behavioral problems in EF during the past 2 months; separate versions of BRIEF exist for preschool- and school-aged children. The BRIEF school-age version (86 items)[16] yields subscale scores for 8 EF domains: (1) inhibit, (2) shift, (3) emotional control, (4) working memory, (5) plan/organize, (6) initiate, (7) organization of materials, and (8) monitor. The BRIEF preschool-age version (63 items)[33] yields subscale scores for the first 5 of those domains. Like LEAF, BRIEF has strong psychometrics as a measure of EF.[16,33] Raw BRIEF scores were converted to T scores using age-based norms from large, nonreferred NH samples.[16] Higher LEAF and BRIEF scores indicate greater EF problems. Parent reporters for LEAF and BRIEF were mother (88.2% of preschool-aged children and 86.0% of school-aged children), father (9.8% of preschool-aged children and 12.0% of school-aged children), or grandmother (2.0% of preschool-aged children and 2.0% of school-aged children).

Statistical Analysis

Results are reported separately for preschool- and school-aged children. First, *t* tests were used to identify domains of EF that differed significantly between the CI and NH samples. Second, to identify the presence of clinically significant EF problems, a value of 1 SD or more above the mean (ie, T score of =60) for the normative (BRIEF) or study NH (LEAF) sample was used as a cutoff for each subscale. Scores that are 1 SD or more above the mean are typically used to identify moderate or greater problems in EF on major behavior checklists,[34] and scores more than 1 SD from the mean are considered to fall outside the average range on many types of psychological tests.[30] Furthermore, children who score more than 1 SD from the mean on measures of EF are considered to be at risk for negative outcomes related to EF.[9] The percentage of children with scores in the clinically significant range of 1 SD or more above the mean was calculated separately for the CI and NH samples in each age range (preschool age and school age). For each age range, we then obtained the relative risk of clinically significant EF problems in CI users by dividing the percentage of clinically elevated scores in the CI sample by the percentage of clinically elevated scores in the NH sample.

Results

EF Behavior

On the basis of *t* tests of LEAF subscale scores, preschool-aged children with CIs were rated as having significantly more problems than children with NH in the areas of comprehension and conceptual learning, factual memory, attention, sequential processing, working memory, and novel problem solving (Table 2). No significant group differences were observed on BRIEF preschool-age subscales between the preschool-aged CI and NH samples. For school-aged children, significant CI vs NH group *t* test differences were found in the same LEAF domains as for preschool-aged children, with the addition of processing speed (Table 2). Furthermore, school-aged children with CIs were rated as having more problems than children with NH on the BRIEF inhibit, shift, emotional control, working memory, initiate, and monitor subscales. At both pre-school and school ages, differences in ratings between CI and NH samples were not found for behaviors that involved visual-spatial organization. Analyses of covariance comparing the CI and NH samples on all LEAF and BRIEF

subscales while controlling for nonverbal IQ produced similar results, with the exception of a nonsignificant result for the LEAF attention sub-scale at preschool ages ($F_{1,47} = 3.220$, $P = .08$, partial $\eta^2 = 0.064$).

Clinical Elevations and Relative Risk of EF Delays

For most LEAF and BRIEF subscales, approximately 38% to 42% or more of the CI sample had clinically elevated scores 1 SD or more above the mean compared with 11% of children with NH (Table 3). Preschool-aged children with CIs were 3.38 (95% confidence interval, 1.03–11.04; LEAF attention subscale) to 11.25 (95% confidence interval, 1.55–81.54; LEAF sustained sequential processing subscale) times more likely than children with NH to have clinical elevations in comprehension and conceptual learning, factual memory, attention, sustained sequential processing, working memory, and novel problem solving on LEAF (Table 3). Preschool-aged children with CIs were at no higher risk than children with NH for clinical elevations on the BRIEF preschool-age subscales. For 7 of the 13 LEAF and BRIEF preschool-age subscales, the relative risk for clinically elevated EF in preschool-aged children was in the range of 2.5 to 4.9 (Table 3). School-aged children with CIs were 2.44 (95% confidence interval, 1.24–4.76; LEAF sustained sequential processing subscale) to 13.53 (95% confidence interval, 1.83–99.56; BRIEF inhibit subscale) times more likely than children with NH to have clinical elevations in scores on the same LEAF subscales as preschool-aged children, as well as in processing speed, and the BRIEF inhibit, shift, emotional control, working memory, plan/organize, and monitor subscales (Table 3). For 12 of the 16 LEAF and BRIEF subscales, the relative risk for clinically elevated EF in school-aged children with CIs ranged from 2.4 to 5.5.

When individual participants had clinical elevations of LEAF or BRIEF subscales, more than one subscale score was usually elevated, suggesting that EF deficits tended to affect multiple related areas of functioning. The number of elevated subscales per participant on LEAF and BRIEF is shown in the Figure. The number of elevated LEAF subscale scores per participant in the CI sample was significantly higher than that of children with NH at both preschool ages (mean [SD] for children with CIs, 3.54 [2.69]; mean [SD] for children with NH, 0.96 [1.77]; $t_{49} = 4.095$; $P < .001$) and school ages (mean [SD] for children with CIs, 3.48 [3.15]; mean [SD] for children with NH, 1.10 [1.92]; $t_{96} = 4.54$; $P < .001$). The mean number of elevated BRIEF subscale scores in the CI sample was significantly higher than that for NH peers but only for the school-aged group (mean [SD] for children with CIs, 2.16 [2.52]; mean [SD] for children with NH, 0.71 [1.24]; $t_{96} = 3.70$; $P < .001$).

Discussion

Our findings indicate that prelingually deaf children with CIs are 2 to 5 times more likely than children with NH to have clinically elevated problems in most domains of EF evaluated in this study based on parent reports of their behavior in real-world situations at home. Across several critical at-risk EF domains, approximately one-third to half of children with CIs were at risk for clinically significant problems compared with approximately one-seventh or fewer of typically developing children with NH. These risks appear to be broad based, involving multiple domains of EF at preschool and school ages, including memory,

attention, sequential processing, novel problem solving, working memory, and conceptual learning. Furthermore, individual children with CIs tended to score within the clinically elevated range on a larger number of EF subscales compared with children with NH. Differences in visual-spatial organization between the CI and NH samples were negligible.

Delays in the CI sample in processing speed, inhibition, shifting, emotional control, planning, and monitoring did not emerge until school ages and were not found on the preschool-age version of BRIEF. This finding may be due to a developmental effect (EF delays worsen with age and time), a cohort effect, or differences in the measurement of EF by LEAF vs BRIEF. Future research with larger sample sizes and longitudinal data are recommended to better understand this finding.

Children with CIs have been found to display weaknesses compared with age-matched controls in multiple domains of EF using clinic-based, neuropsychological tests.[9] The results of the current study extend the findings of this research beyond the laboratory and clinic settings into the realm of real-world, day-to-day functional behaviors. Such findings provide clinically relevant, ecologically valid evidence that broad domains of EF are affected by auditory deprivation and language delays. Research suggests that the development of EF is critically dependent on exposure to sequential signals from sensory (particularly auditory) experience[12] and use of spoken language skills to facilitate controlled attention and planning.[28,35] Hence, the present findings are consistent with earlier research that reported links among auditory deprivation, language delay, and EF delay and further extend this research to functional, real-world EF outcomes.

The results of this study should be interpreted in the context of several study characteristics and limitations. First, all data were based on parent-reported measures, which can be subject to reporter bias. However, parent-reported measures of EF have been found to have excellent reliability and validity and correspond well to behaviors of clinical concern.[16] Second, because LEAF lacks a large, representative normative sample, we used our NH control sample to derive T scores for LEAF subscales. As a result, LEAF T scores indicate deviations relative to the NH control sample and not to a large, representative normative sample. Nevertheless, comparisons using LEAF scores are appropriate for identifying differences between demographically comparable CI and NH samples. Third, differences in EF between groups may have been influenced by unknown confounding variables. The effects of potential known confounding variables were minimized by using groups recruited from similar settings, which did not differ in age, sex, or socioeconomic status. Furthermore, although the preschool-aged CI and NH groups differed in nonverbal IQ, study results remained similar when nonverbal IQ was statistically controlled. Fourth, because this study used a cross-sectional design, differences between age groups could be confounded by cohort effects, such as advances in CI technology. Fifth, the preschool-aged sample size may not have been sufficient to detect significant small to medium effect sizes. Sixth, additional research is needed to investigate potential relations between hearing history and EF outcomes in children with CIs. However, in post hoc correlational analyses of the current data, demographic and hearing history variables (Table 1) were generally unrelated to LEAF and BRIEF EF scores in CI users, consistent with past studies using neurocognitive measures of EF.[9] Specifically, those correlations were not statistically significant at a rate

higher than chance (<5% of the correlations were significant at $P < .05$; see eTable 1 and eTable 2 in the Supplement).

Conclusions

Hearing loss is one of the most common conditions of childhood,[36] and most children with severe to profound pre-lingual sensorineural hearing loss receive CIs.[37] By demonstrating that the risk of EF deficits in children with CIs is 2 to 5 times that of children with NH in many EF domains, this study provides important guidance for the evaluation and management of outcomes after cochlear implantation. Furthermore, because of the contribution of auditory and language deprivation in these findings, broader samples of children with mild to moderate hearing loss and/or language delays may also be at risk for these types of functional, day-to-day EF deficits. Our findings provide support for changes in early intervention and habilitation after cochlear implantation, such as (1) increased awareness by parents, educators, health care professionals, and speech-language pathologists that one-third to half of children who use CIs are at risk for developing problems in at-risk domains of EF; (2) development and use of EF assessment instruments and protocols that are valid, inexpensive, and easily and quickly administered by educators and therapists; and (3) development of targeted interventions that can be used throughout the habilitation process designed to improve EF skills. Currently, habilitation and intervention after cochlear implantation focus primarily on speech and language; programs that target EF skills are also needed with this clinical population.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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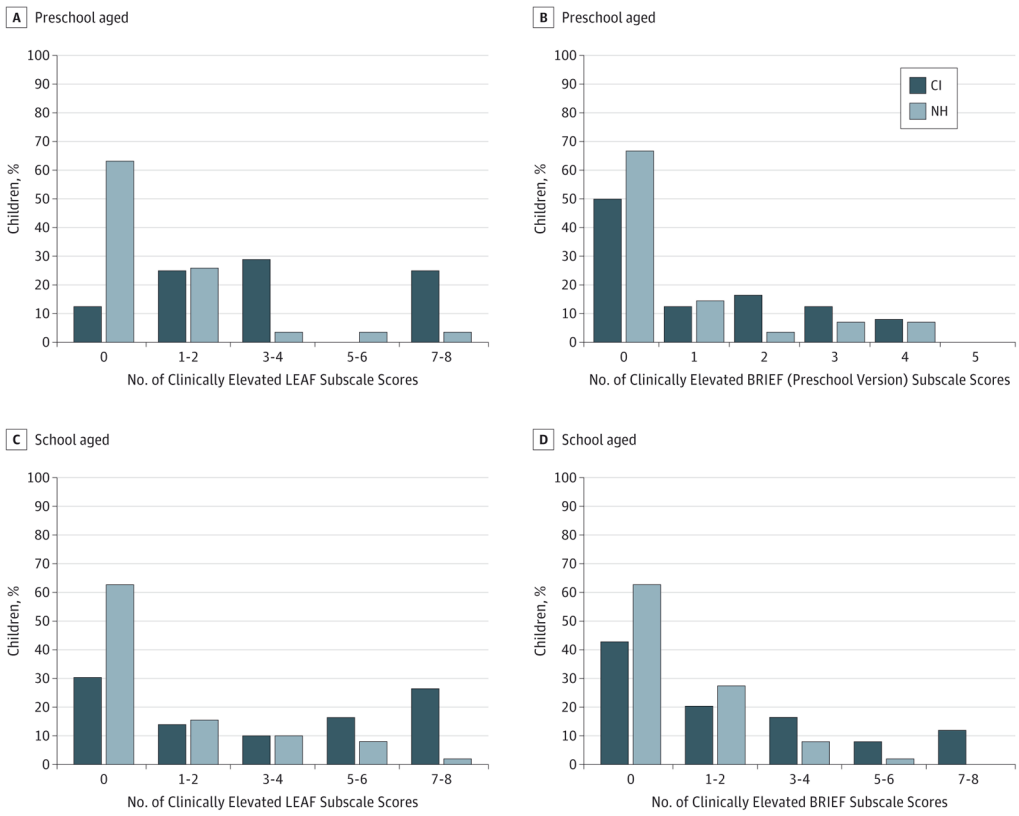

Figure. Number of Clinically Elevated Executive Function Subscale Scores

Figure shows the percentage of children in each group (cochlear implant [CI] and normal hearing [NH]) with clinically elevated executive functioning on 1 or more subscales: Learning, Executive, and Attention Functioning Scale (LEAF) scores (A) and Behavior Rating Inventory of Executive Functioning (BRIEF) (preschool version) scores (B) in preschool-aged children (3–5 years old) and LEAF (C) and BRIEF (D) scores in school-aged children (7–17 years old).

Table 1

Demographic Characteristics and Hearing History

Characteristic	Preschool Age (3–5 Years Old)		School Age (7–17 Years Old)	
	Cochlear Implant (n = 24)	Normal Hearing (n = 27)	Cochlear Implant (n = 49)	Normal Hearing (n = 51)
Mean (SD)				
Onset of deafness, mo	0		0.59 (2.77)	
Age at implantation, mo	18.79 (8.44)		28.17 (13.91)	
Duration of CI use, y	2.55 (0.89)		10.29 (2.28)	
Age at testing, y	4.12 (0.83)	3.99 (0.63)	12.64 (2.66)	12.94 (2.66)
Preimplantation PTA[a]	100.85 (13.54)		107.18 (11.56)	
Communication mode[b]	4.75 (0.85)		4.59 (0.98)	
Nonverbal IQ[c]	54.48 (9.61)	61.89 (14.20)	54.63 (7.97)	55.47 (7.61)
Income level[d]	6.73 (3.06)	7.19 (2.15)	7.4 (2.38)	7.55 (2.28)
No. (%)				
Hearing device				
Bilateral CI	16 (66.6)		19 (38.8)	
Bimodal (CI and hearing aid)	1 (4.2)		1 (2.0)	
Unilateral CI	7 (29.2)		29 (59.2)	
Sex				
Female	10 (41.7)	14 (51.9)	22 (44.9)	29 (56.9)
Male	14 (58.3)	13 (48.1)	27 (55.1)	22 (43.1)
Race				
Black/African American	2 (8.3)	2 (7.4)	0	8 (15.7)
Asian	0	0	2 (4.1)	2 (3.9)
Multiracial	3 (12.5)	1 (3.7)	2 (4.1)	5 (9.8)
White	19 (79.2)	24 (88.9)	45 (91.8)	36 (70.6)
Ethnicity				
Hispanic	1 (4.2)	1 (3.7)	2 (4.1)	1 (2.0)
Not Hispanic	23 (95.8)	26 (96.3)	47 (95.9)	50 (98.0)

Abbreviations: CI, cochlear implant; PTA, pure-tone average.

[a] Unaided PTA in the better ear for the frequencies 500, 1000, and 2000 Hz in decibels of hearing loss.

[b] Communication mode is coded on a scale from mostly sign (coded 1) to auditory-verbal (coded 6) with a code of 4 indicating cued speech.[29]

[c] T score from Differential Ability Scale II picture similarities subtest for preschool-aged children and T score from Wechsler Abbreviated Scale of Intelligence matrix reasoning subtest for school-aged children.

[d] Income level is coded on a scale from less than $5000 (coded 1) to $95 000 or higher (coded 10) with a code of 6 indicating $35 000 to $49 999 and a code of 7 indicating $50 000 to $64 999.

Table 2

Mean (SD) Executive Functioning Scores by Age Group and Hearing Status

	Preschool Age (3–5 Years Old)			School Age (7–17 Years Old)		
Subscale	**Cochlear Implant (n = 24)**	**Normal Hearing (n = 27)[a]**	***P* Value**	**Cochlear Implant (n = 48)**	**Normal Hearing (n = 50)[a]**	***P* Value**
LEAF						
Comprehension and conceptual learning	91.07 (35.15)	50 (10)	<.001	70.23 (21.19)	50 (10)	<.001
Factual memory	65.35 (19.11)	50 (10)	.001	63.66 (24.10)	50 (10)	<.001
Attention	57.33 (10.39)	50 (10)	.01	64.04 (19.75)	50 (10)	<.001
Processing speed	52.34 (8.99)	50 (10)	.39	55.84 (13.01)	50 (10)	.01
Visual-spatial organization	53.67 (13.73)	50 (10)	.28	51.02 (8.60)	50 (10)	.60
Sustained sequential processing	59.61 (16.14)	50 (10)	.01	59.45 (15.38)	50 (10)	<.001
Working memory	63.07 (13.51)	50 (10)	<.001	62.02 (20.62)	50 (10)	<.001
Novel problem solving	62.10 (12.82)	50 (10)	<.001	66.82 (26.12)	50 (10)	<.001
BRIEF (preschool- and school-age versions)[b]						
Inhibit	56.38 (13.21)	50.11 (9.28)	.05	53.86 (11.44)	45.90 (6.03)	<.001
Shift	51.38 (7.87)	47.30 (8.61)	.09	52.63 (11.12)	45.71 (10.34)	.002
Emotional control	49.71 (8.31)	45.44 (6.93)	.05	51.78 (12.42)	45.88 (9.12)	.008
Working memory	57.88 (12.07)	52.44 (13.40)	.14	53.84 (10.87)	48.59 (9.46)	.01
Plan/organize	50.29 (11.29)	49.30 (10.71)	.75	51.94 (11.34)	48.55 (9.29)	.11
Initiate				52.86 (11.39)	48.14 (8.99)	.02
Organization of materials				50.18 (10.39)	49.86 (10.07)	.88
Monitor				51.57 (11.22)	46.33 (9.47)	.01

Abbreviations: BRIEF, Behavior Rating Inventory of Executive Function; LEAF, Learning, Executive, and Attention Functioning Scale.

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[a] Means (SDs) for the LEAF subscales for the normal-hearing samples are all 50 (10) because norms for calculating T scores were derived from the normal-hearing samples (see the Methods section).

[b] The preschool-age version of BRIEF is administered to preschool-aged children and includes only 5 subscales.

Table 3

Relative Risk of Clinically Significant Executive Functioning Deficits in Children With Cochlear Implants

	Preschool Age (3–5 Years Old)			School Age (7–17 Years Old)		
	Clinically Elevated Scores, %[a]		Relative Risk (95% Confidence Interval)[b]	Clinically Elevated Scores, %		Relative Risk (95% Confidence Interval)[b]
Characteristic	CI (n = 24)	NH (n = 27)		CI (n = 48)	NH (n = 50)	
LEAF						
Comprehension and conceptual learning	79.2	22.2	3.56 (1.71–7.43)	61.2	9.8	6.25 (2.64–14.77)
Factual memory	54.2	11.1	4.88 (1.58–15.07)	42.9	7.8	5.47 (2.03–14.77)
Attention	37.5	11.1	3.38 (1.03–11.04)	49.0	15.7	3.13 (1.56–6.26)
Processing speed	8.3	11.1	0.75 (0.14–4.12)	40.8	13.7	2.98 (1.39–6.39)
Visual-spatial organization	29.2	11.1	2.63 (0.76–9.03)	18.4	17.6	1.04 (0.45–2.40)
Sustained sequential processing	41.7	3.7	11.25 (1.55–81.54)	42.9	17.6	2.44 (1.24–4.76)
Working memory	45.8	11.1	4.13 (1.30–13.06)	42.9	11.8	3.64 (1.61–8.25)
Novel problem solving	58.3	14.8	3.93 (1.50–10.34)	42.9	13.7	3.13 (1.46–6.67)
BRIEF (preschool- and school-age versions)						
Inhibit	37.5	14.8	2.53 (0.89–7.17)	26.5	2.0	13.53 (1.83–99.56)
Shift	8.3	11.1	0.75 (0.14–4.11)	24.5	7.8	3.12 (1.08–9.03)
Emotional control	12.5	0		28.6	7.8	3.64 (1.29–10.30)
Working memory	45.8	25.9	1.77 (0.82–3.83)	32.7	11.8	2.78 (1.18–6.51)
Plan/organize	12.5	22.2	0.56 (0.16–2.01)	28.6	7.8	3.64 (1.29–10.30)
Initiate				22.4	7.8	2.86 (0.98–8.39)
Organization of materials				24.5	17.6	1.39 (0.64–3.00)
Monitor				28.6	7.8	3.64 (1.29–10.30)

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Abbreviations: BRIEF, Behavior Rating Inventory of Executive Function; CI, cochlear implant; LEAF, Learning, Executive, and Attention Functioning Scale; NH, normal hearing.

[a] Clinically elevated is 1 or more SDs above the normative mean (T score ≥60).

[b] Relative risks are statistically significant at $P < .05$ when the lower bound of this confidence interval is greater than 1.