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Effects of Age at Implantation on Outcomes of Cochlear Implantation in Children with Short Durations of Single-Sided Deafness

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Objective: Children with single-sided deafness (SSD) show reduced language and academic development and report hearing challenges. We aim to improve outcomes in children with SSD by providing bilateral hearing through cochlear implantation of the deaf ear with minimal delay.

Study Design: Prospective cohort study of 57 children with SSD provided with cochlear implant (CI) between May 13, 2013, and June 25, 2021.

Setting: Tertiary children's hospital.

Participants: Children with early onset (n = 40) or later onset of SSD (n = 17) received CIs at ages 2.47 ± 1.58 years (early onset group) and 11.67 ± 3.91 years (late onset group) (mean ± SD). Duration of unilateral deafness was limited (mean ± SD = 1.93 ± 1.56 yr).

Intervention: Cochlear implantation of the deaf ear.

Main Outcomes/Measures: Evaluations of device use (data logging) and hearing (speech perception, effects of spatial release from masking on speech detection, localization of stationary and moving sound, self-reported hearing questionnaires).

Results: Results indicated that daily device use is variable (mean ± SD = 5.60 ± 2.97, range = 0.0–14.7 h/d) with particular challenges during extended COVID-19 lockdowns, including school closures (daily use reduced by mean 1.73 h). Speech perception with the CI alone improved (mean ± SD = 65.7 ± 26.4 RAU) but, in the late onset group, remained poorer than in the normal hearing ear. Measures of spatial release from masking also showed asymmetric hearing in the late onset group (t_{13} = 5.14, p = 0.001). Localization of both stationary and moving sound was poor (mean ± SD error = 34.6° ± 16.7°) but slightly improved on the deaf side with CI use ($F_{1,36}$ = 3.95, p = 0.05). Decreased sound localization significantly correlated with poorer self-reported hearing.

Conclusions and Relevance: Benefits of CI in children with limited durations of SSD may be more restricted for older children/adolescents. Spatial hearing challenges remain. Efforts to increase CI acceptance and consistent use are needed.

Key Words: Unilateral hearing loss—Single-sided deafness—Cochlear implant—Electrical-acoustic bimodal hearing—Binaural—Children—Adolescent—Prelingual—Postlingual—Speech perception—Spatial hearing—Sound localization.

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INTRODUCTION

We aimed to improve hearing in children and adolescents with single-sided deafness (SSD) by providing a cochlear implant (CI) in the deaf ear with limited delay.

Developmental Challenges in Children with Unilateral Hearing Loss

Permanent hearing loss affects 1 to 3/1000 children, and approximately 40% to 50% have unilateral impairment (1,2). This asymmetric hearing disrupts access to binaural cues, which contributes to increased challenges locating and separating sounds by their spatial position and detecting and understanding speech in noise (3). Many studies highlight hearing challenges in children with unilateral hearing loss and advocate clinical care (4–7). Children with severe to profound unilateral hearing loss, often referred to as SSD, require particular attention because they have essentially no binaural/spatial hearing and because treatment options for their hearing loss are limited. Indeed, without intervention, children with SSD show developmental deficits in learning and memory that are comparable with peers who are bilaterally deaf and have used bilateral CIs from young ages (8). Because bilateral CIs do not restore normal access to interaural cues (particularly interaural timing differences) even when provided without delay (9–11),

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comparable deficits in development between children with bilateral CIs and children with SSD further supports the importance of binaural/spatial hearing in development (12) and emphasizes the need for treatment of unilateral sensorineural hearing loss, including SSD, in children.

Cochlear Implantation in Children with SSD: Why and When?

In the present study, CIs were provided to children in an effort to reduce the developmental effects of SSD. Bone conduction devices are another treatment option, potentially increasing access to sound on the deaf ear, but CIs provide a unique opportunity to stimulate the auditory pathways from both ears (13). We also considered the timing of cochlear implantation given evidence of deterioration to auditory pathways if left deprived of sound and developmental adaptations to the deafness (14). In children with bilateral deafness, an "aural preference" for the stimulated ear is established in the auditory pathways by unilateral CI use (12). This contributes to asymmetric hearing that is difficult to reverse despite providing bilateral hearing through two CIs later (12). There are only limited reports of CI in children with SSD at present, but early data suggest better benefits in children implanted at younger rather than older ages (15,16). However, because age at SSD onset and durations of SSD have been variable across the reported cohorts, the effects of the duration of deafness versus age-related differences in plasticity remain unclear. These questions are beginning to be addressed by a large group of children with SSD who received a CI with limited delay in our center. We have reported unique CI candidacy considerations related to SSD, including pathogenesis of deafness and parental decision making (17). In addition, we raised some concerns related to implantation in the older children in our cohort who experienced postlingual onset of SSD (18). Although this group had the advantage of having normal binaural hearing in early stages of development, there are signs that they may be experiencing significant challenges of SSD. Hours of daily CI use measured through data logging measures can be slightly reduced in this older group compared with their younger peers (18,19). There are also developmental differences in responses from auditory cortices; although the CI stimulates the development of cortical representation from the deaf ear in the young group with early onset SSD, the older group shows ongoing deterioration of input from the deaf ear despite CI use (18).

Cochlear Implantation in Children with SSD: Benefits for Spatial Hearing?

Benefits of CI use for binaural/spatial in individuals with SSD might also be impeded by using bimodal input (CI in one ear and acoustic hearing in the other). Evidence from individuals with bimodal hearing through a CI and a hearing aid indicate large mismatches in place, level, and timing of interaural stimulation that are the likely cause of continuing deficits in binaural/spatial hearing in bimodal users (20–22). The localization of both stationary and moving sound appears to improve slightly, but significantly, with CI use in adult SSD users (23,24), and discrimination of front versus back sounds can be improved with head movement (25). Less is known about the effects of CI use on spatial hearing in children with SSD. Initial reports suggest modest abilities to locate sounds with and without a CI (26–28).

In the present report, we ask whether there are benefits of CI based on age at CI in our cohort of children with limited durations of SSD. We hypothesize that older children/adolescents with late onset SSD 1) use their CIs less than children with early onset SSD and 2) experience more hearing challenges as measured by speech perception, speech detection in noise, sound localization, and the Speech, Spatial, and Qualities of Hearing Scale (SSQ).

MATERIALS AND METHODS

This prospective clinical cohort study was conducted under the Research Ethics Board of this institution (no. 1000002954), which adheres to the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans.

Participants

Participants were 57 children with either early (prelingual) onset (n = 40: 19 cytomegalovirus, 9 genetic, 3 meningitis, and 9 unknown) or later (postlingual) onset of SSD (n = 17) (4 trauma, 2 cytomegalovirus, 2 cholesteatoma, 2 meningitis, 1 horizontal semi-circular canal erosion, and 6 unknown) received a nucleus CI (Cochlear Ltd., Sydney, Australia) in the deaf ear at ages 2.47 ± 1.58 years (early onset group) and 11.67 ± 3.91 years (late onset group) mean ± SD. The duration of unilateral deafness was limited in the full cohort (both groups) (mean ± SD = 1.93 ± 1.56 yr). Inclusion was determined through our program's multidisciplinary assessment of CI candidacy (29,30), which identifies areas of concern for CI use in 14 categories spanning from audiological to medical to psychosocial and educational issues. Exclusionary criteria were hearing thresholds >25 dB HL in the better hearing ear, use of a hearing aid in the better hearing ear, duration of SSD exceeding 4 years, and developmental delay precluding potential to participate in study outcome measures. All CI recipients in our program, including those in the present cohort, receive access to auditory–verbal therapy. Outcome measures included data logs of device use, speech perception in quiet and noise, localization of stationary and moving sound, and self-reported hearing. Follow-up testing occurred in concert with the clinical follow-up at the following intervals after CI activation: 1 week, 1 month, 3 months, 9 months, 1 year, and at least once annually thereafter. Incomplete data reflect limitations in age/ability to participate and/or ability to travel to our CI center or to stay for testing.

Data logging

As in past work (31–33), data logging of daily CI use was used to assess acceptance of the CI in children with SSD. Average daily hours of use were measured between successive data log captures either during a programming visit to the implant center or through a remote check system (Cochlear™ Remote Check). The cumulative dose was the sum of all doses (average daily hours × days of data log) measured at each data log capture. Data logs were excluded if the period between captures was less than 14 days. The number of data logs ranged between 1 and 11 for each participant prepandemic (before March 2020) and between 1 and 3 postpandemic (March 2020 and later). Data logs were collected from the CI in 53 children (37 in the early onset group and 16 in the late onset group)

Speech Perception and Detection

Speech perception was measured using Word Intelligibility by Picture Identification (34), Multisyllabic Lexical Neighborhood Test, Lexical Neighborhood Test, or Phonetically Balanced Kindergarten Word (35,36) tests. Speech was presented either by a recorded test version or by monitored live voice at 60 to 65 dB SPL from a loudspeaker at 0° azimuth in two listening conditions: normal hearing (NH) ear alone and bimodal (NH open and CI on) × 2 auditory conditions: quiet (speech alone) and noise (speech weighted noise at 55 dB SPL, signal-to-noise ratio [SNR] = 10 dB, from the same loudspeaker at 0° azimuth). The CI alone was tested in the same set up with the NH ear plugged and muffed or masked with speech noise at 55 dB SPL through an insert earphone or by delivering speech stimuli at 60 to 65 dB SPL to the line-in port of the Cochlear Wireless Mini Microphone paired to the CI.

Spatial release from masking (SRM) was measured with CI on. Recorded spondee words were presented from a loudspeaker at 0° azimuth. Speech weighted noise was presented at a fixed level of 45 dB HL from a loudspeaker at 0° azimuth or from a loudspeaker 90° azimuth to the left or a loudspeaker 90° azimuth to the right of the participant. Loudspeakers were calibrated to ANSI 3.62018 standards. Speech recognition thresholds were determined using a bracketing procedure with 2 dB HL step changes in the speech presentation. Speech perception and detection measures were available from 31 (20 early onset and 11 late onset) children.

Stationary and Moving Sound Localization

Sound localization was measured across an arc of 120° in the horizontal plane from −60° (left) to +60° (right) azimuth. A 1-m long L-shaped arm held a speaker fixed at the distal end 1.15 m from the floor. The proximal end of the speaker arm was fixed to a silent-stepper motor (57BYGH420-2 Wantai Motor), allowing the speaker to move to any position within the arc. Participants sat directly beneath the motor on a height-adjustable nonswivel stool. All equipment was visually hidden from participants by black acoustically transparent cloth. Stimuli were white noise (125–8,000 Hz), and level was roved between −4 and +4 dB SPL. Stimuli were presented in 10 blocks of six trials in two conditions (CI off and CI on). Each trial had two components: 1) stationary sound at location 1 (L1) anywhere within ±60° for 3.0 s and then 2) continuous sound moving from L1 to a second position (L2) at 40°, 20°, or 0° rightward or leftward in pseudorandom order. The duration of moving stimuli varied between 3.22 and 9.03 s, based on the magnitude of position change from L1 to L2, but was not dependent on where L1 was located [estimate (SE) = 0.009 (0.009), $p = 0.34$]. Participants were asked to locate L1 ("Where is the sound?") and L2 ("Where did the sound move to?") by moving a red laser dot projected onto the black curtain situated in front of them using a Logitech Gamepad F310 videogame controller (possible arc from −90° to +90°). The position of the laser point was measured.

Sound localization was measured in 12 participants who were willing and able to complete this testing (n = 3 early onset and 9 late onset).

Self-Reported Hearing Questionnaire

The SSQ was used to assess self-reported hearing. The adolescent version was used by participants who could complete the questionnaire themselves, and the parent version was provided to parents/caregivers of participants. Both versions were completed for four participants. The SSQ was completed repeatedly when possible between 0.05 and 6.6 years of CI use. At least one version of the SSQ (parent and/or adolescent) was completed in 35 of the 40 early onset group and 13 of the 17 late onset group. Missing data are from children who were lost to follow-up.

Analyses

Using R-studio (version 1.3.1093), mixed model regressions were tested with ANOVA for main effects and interactions using Satterthwaite's method. Contrasts of significant effects were tested using the contrasts or emmeans function of package emmeans; degrees of freedom were adjusted using the Kenward–Roger method, and *p* values were adjusted using the Tukey method. Perception of moving sound direction was assessed using the Gaussian regression of the proportion of rightward responses.

RESULTS

Models and results of ANOVAs (type III analysis of variance table with Satterthwaite's method) are provided in Table 1. Relevant findings are discussed for each outcome measure below.

Data logging

Data logs were collected from the CI in 53 children. Figure 1A shows daily CI use over time since CI activation. There was no difference in daily CI use between groups ($t_{47.17} = 0.30$, $p = 0.76$) but a slight decrease over time from initial activation [intercept (SE) = 6.15 (0.45) daily hours] at a rate of [estimate (SD) = −0.039 (−0.013) h/mo CI use, $t_{181.10} = 2.93$, $p = 0.0039$]. Figure 1B plots the total CI dose, which accounts for both duration of use since activation and daily hours of CI use; no group differences were found on this measure either ($F_{1, 51} = 1.73$, $p = 0.19$).

Daily CI use relative to the COVID-19 pandemic (pre- versus post-March 2020) was available in 35 participants (26 early onset and 9 late onset) and, as shown in Figure 1C, revealed a significant decrease [estimate (SE) = −1.48 (0.70) h] of daily CI use during the peripandemic period ($F_{1,19}$=6.64, $p = 0.018$). Based on limited data (n = 3), the late onset group

TABLE 1. *ANOVA results of mixed model regressions (lmer)*

Factor	Sum of Squares	Mean Sq	NumDF	DenDF	*F*	Pr (>F)	Significance
A. [Speech Perception]: RAU ~ Group × Side × Test Condition + (1|Participant)							
Group (early onset/late onset)	164.8	164.8	1	24.209	0.6106	0.4421	NS
Side (CI/NH/bimodal)	11476.4	5738.2	2	78.414	21.2566	4.21E−08	***
Test condition (quiet/noise)	4,497	4,497	1	78.221	16.6588	0.000107	***
Group–side	6616.3	3308.2	2	78.414	12.2547	2.34E−05	***
Group–test condition	301.2	301.2	1	78.221	1.1158	0.294	NS
Side–test condition	1,628	814	2	76.829	3.0154	5.49E−02	.
Group–side–test condition	332.6	166.3	2	76.829	0.616	0.5427	NS
B. [Spatial Release from Masking]: SRM ~ Group × Side + (1|Participant)							
Group (early onset/late onset)	1.995	1.995	1	13	0.4577	0.51	NS
Side (CI/NH side)	82.689	82.689	1	13	18.9659	7.00E−04	***
Group–side	56.672	56.672	1	13	12.9986	0.0031	**
C. [Stationary Sound Localization by Trial/Position]: Perceived Position ~ Speaker Position × Testing Condition + (1|Participant)							
Speaker position (between ±60°)	212,250	212,250	1	1158.72	420.447	<2.2E−16	***
Testing condition (CI on/off)	1,043	1,043	1	12.14	2.0654	1.76E−01	NS
Speaker position–testing condition	4,356	4,356	1	1158.75	8.6282	0.003375	**
D. [Stationary Sound Localization by RMSE]: RMSE ~ Side × Testing Condition + (1|Participant/Testing Condition)							
Side (CI/NH side)	707.35	707.35	1	36	4.6337	0.03813	*
Testing condition (CI on/off)	303.34	303.34	1	36	1.9871	0.16723	NS
Side–testing condition	602.87	602.87	1	36	3.9492	0.05454	.
E. [Moving Sound Localization/Direction of Sound Movement Measured by the Proportion of Responses Judged Moving Right]: Accuracy ~ Speaker Position Change + Testing Condition + (1|Participant)							
Speaker position change	16.4216	16.4216	1	2091	711.983	<2.2E−16	***
Testing condition	0.2773	0.2773	1	2091	12.023	0.000536	***
F. [Moving Sound Localization/Direction of Sound Movement Measured by Logit Slopes]: Slope ~ Testing Condition × Group + (1|Participant)							
Testing condition	0.00132	0.00132	1	7	0.9455	0.3633	NS
Group (early onset/late onset)	7.08E−05	7.08E−05	1	7	0.0507	0.8282	NS
Testing condition–group	0.005608	0.005608	1	7	4.0167	0.0851	.
G. [SSQ × RMSE]: SSQ Score ~ RMSE + SSQ Category + (1|Participant)							
RMSE	21.2512	21.2512	1	7	12.753	0.009083	**
SSQ category	6.2498	3.1249	2	16	1.8753	1.85E−01	NS
H. [SSQ x Slope]: SSQ Score ~ Slope + SSQ Category + (1|Participant)							
Slope	0.0056	0.0056	1	48.471	0.0044	0.94733	NS
SSQ category	12.4996	6.2498	2	42.169	4.9331	1.19E−02	*

RMSE, root-mean-square error.
Dots indicate trend ($p < 0.10$) as per output of R-studio statistical software (listed in methods).

showed reduced daily CI use compared with the early onset group ($F_{1,19}$=8.82, p = 0.0078). We identified 22 (9 early onset; 13 late onset) children who were using their CI for <3 hours daily based on most recent data logs and feedback from the managing audiologists. Clinical follow-up and support, including auditory–verbal therapy, counseling, and assistance for daycare and school staff, are ongoing.

Speech Recognition in Quiet and Noise

Speech perception was measured in 31 (20 early onset and 11 late onset) children. As shown in Figure 2A, children in the early onset group showed similar speech perception scores between the hearing conditions (NH-CI: $t_{83.4}$ = 0.78, p = 0.97; NH-Bimodal: $t_{79.1}$ = −0.83, p = 0.96; CI-Bimodal: $t_{86.3}$ = −1.43, p = 0.71). By contrast, the late

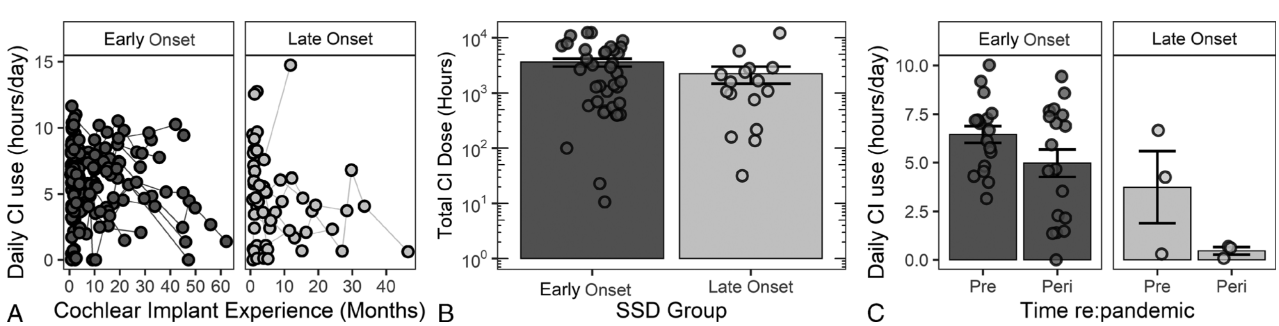

FIG. 1. *A*, Averaged daily hours of cochlear implant (CI) use per day with ongoing CI use during the prepandemic period (before march 2020), plotted for both early and late SSD onset groups (n = 49), show a slight reduction in daily use with time (p = 0.0039) with no significant group differences (p = 0.76). *B*, The total cumulative CI dose prepandemic was also similar between groups (p = 0.19). *C*, Data logs gathered in a subset of children with both pre- and peripandemic data logs, plotted individually (dots) and by boxplot, show significant reductions in average hours of daily use during pandemic (p = 0.018).

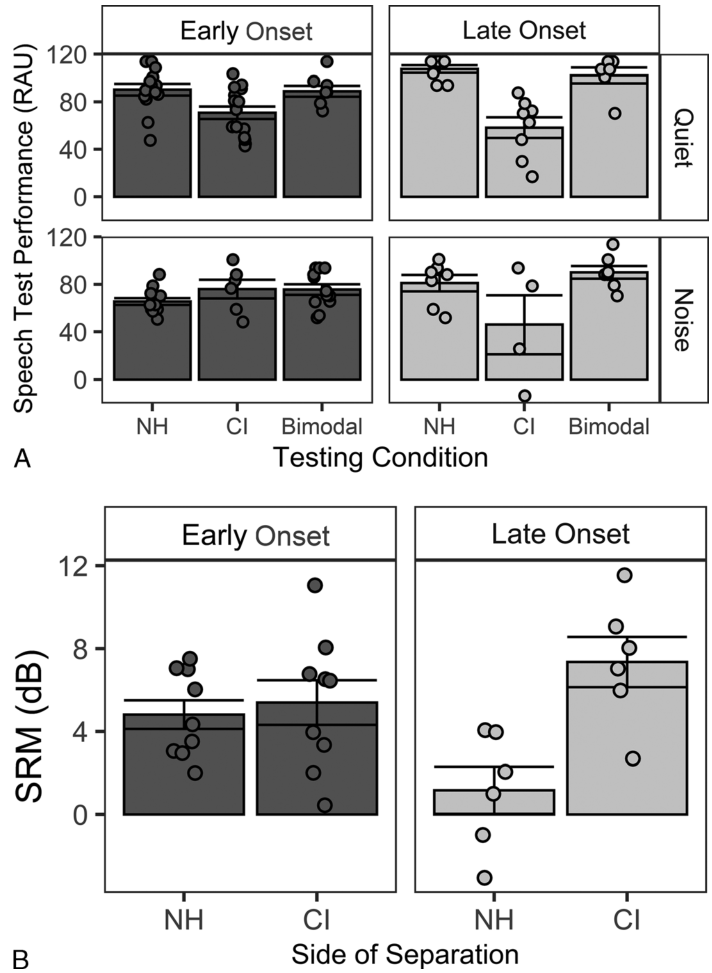

FIG. 2. *A*, Accuracy (RAU) of speech testing is plotted for acoustic, CI, and bimodal conditions in speech (*left*) and noise (*right*). *B*, Changes in signal-to-noise ratio for speech reception thresholds between noise at colocated versus +90° or −90° azimuth are calculated as spatial release from masking (SRM). Mean ± SE data (*bars*) and individual data show symmetric improvements in the early onset group ($p = 0.93$), but asymmetric results in the late onset group as benefits of spatial separation are significantly reduced when noise is moved toward the side of the normal hearing ear in this group ($p = 0.001$).

onset group retained asymmetric hearing with poorer scores in the CI condition [NH-CI: estimate (SE) = −43.95 (6.82), $t_{81.1} = 6.45$, $p < 0.0001$; CI-Bimodal: estimate (SE) = −45.92 (7.00); $t_{78.9} = -6.56$, $p < 0.0001$]. Scores in the children in the late onset compared with the early onset group were slightly better in the NH ear [estimate (SE) = 17.96 (6.54); $t_{59.5} = -2.75$, $p = 0.08$] and slightly poorer in the CI [estimate (SE) = 21.83 (7.58); $t_{78.7} = 2.88$, $p = 0.056$]. There were no significant differences in bimodal scores between the groups ($t_{67} = -2.17$, $p = 0.26$). Speech perception was significantly affected by noise in the late onset group [estimate (SE) = 17.99 (5.48); $t_{78.2} = 3.28$, $p = 0.008$] but not in the early onset group ($t_{81.4} = 2.40$, $p = 0.08$).

Speech recognition thresholds were obtained in three noise conditions (colocated with speech at 0° azimuth and separated from the speech by moving to −90° and to +90° azimuth) in 16 (9 early onset and 7 late onset) children. The difference in SNR between the conditions of colocated and separated noise, called the spatial release from masking (SRM *dB*), are plotted for each group in Figure 2B. Positive numbers indicate the improved SNR produced by spatial separation of the noise. In the early onset SSD group, the SRM was similar for noise moved toward the NH ear and for noise moved to the CI side ($t_{13} = 0.60$, $p = 0.93$). In the late onset SSD group, however, SRM was reduced when noise moved to the NH side rather than to the side of the CI ($t_{13} = 5.14$, $p = 0.001$).

Sound Localization

Sound localization was measured in 12 participants (n = 9 late onset and 3 early onset). Response positions to stationary sound are plotted again stimulus position in Figure 3A for each child. As shown in Figure 3B, the accuracy of localizing the stationary sound was poor as measured by high root-mean-square error (°) in most participants with both the CI on and the CI off [estimate (SE) = 1.98 (4.85)]. Participants in the early onset cohort had larger error rates compared with late onset peers [estimate (SE) = 29.6 (0.02)]. Error was higher in the hemifield on the side of the deaf ear than the opposite hemifield

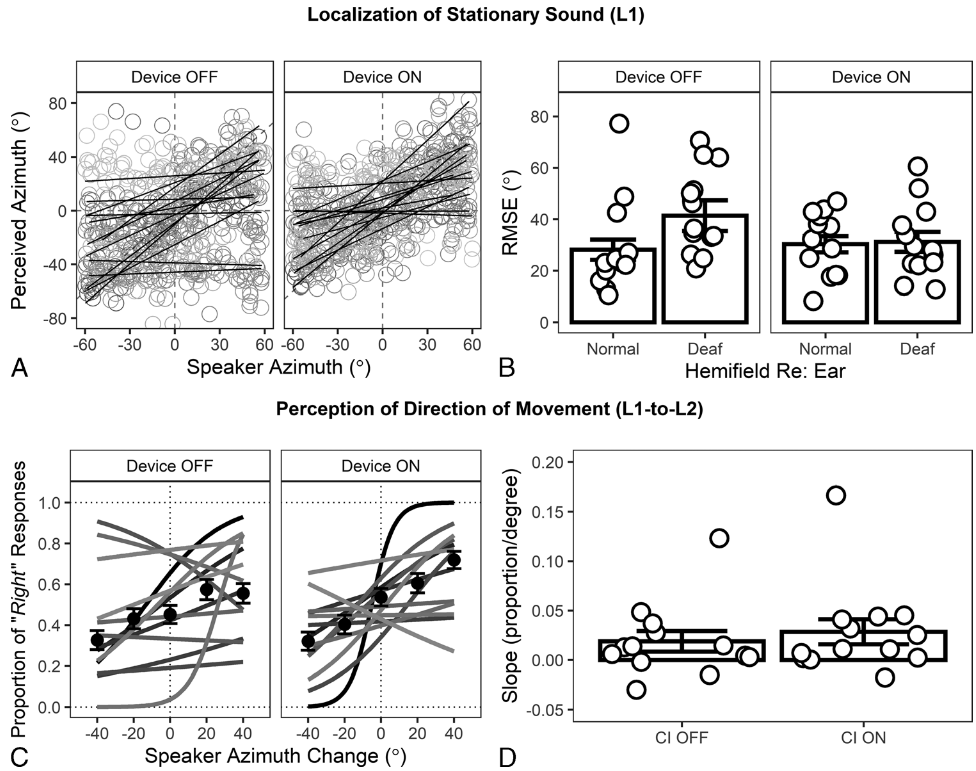

FIG. 3. *A*, Response position plotted against speaker position for stationary sound at location 1 (L1) reveals individual variability. *B*, Root-mean-square error of stationary localization data reveals high error, which is increased on the side of the deaf ear when the CI is off ($p = 0.05$). *C*, Direction of sound movement based on change in response from L1 to a second position L2 is measured as the proportion of rightward responses and plotted against degree of leftward (negative values) or rightward (positive values) moving sound. Individual data modeled by the Gaussian regression are shown, revealing high variability. *D*, Slopes of Gaussian models from C are shallow (low numbers) in both groups, indicating poor perception of moving sound direction with or without the CI ($p = 0.31$).

[estimate (SE) = 16.1 (7.34)]. The accuracy of perceiving correct movement direction from L1 to L2 is shown by the proportion of rightward responses in Figure 3C. Gaussian regression curves reveal shallow slopes, plotted in Figure 3D, indicative of little change in perception between rightward and leftward moving sound [estimate (SE) = 0.0037 (0.00014) across device conditions]. There was no significant difference in the slopes between groups [estimate (SE) = 0.05 (0.04)] or between CI on versus off conditions [estimate (SE) = 0.02 (0.02)].

Self-Reported Hearing

The SSQ adolescent version was completed by 13 children [11 late onset and 2 early onset] children, and the parental version was completed by parents/caregivers for 39 children (4 late onset and 35 early onset). Scores for each subtest are shown in Figure 4A. There were no significant differences in scores provided the adolescent versus the parent/caregiver versions ($F_{1,344} = 1.37$, $p = 0.24$). There was an interaction between subtests and group ($F_{2,312} = 6.82$, $p = 0.0013$), revealing poorer self-reported

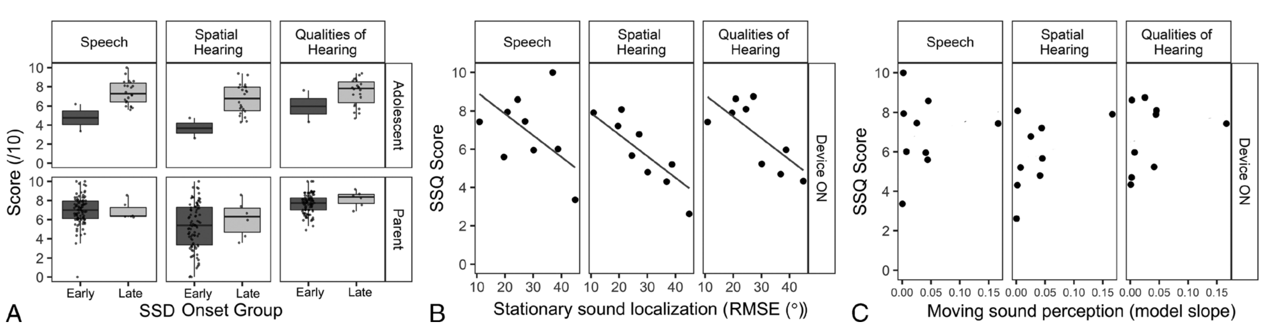

FIG. 4. *A*, Scores from parent and child/adolescent versions of the Speech, Spatial, and Qualities of Hearing Scale (SSQ) show no significant differences between versions ($p = 0.24$) or groups ($p = 0.11$). Both early onset and late onset groups reported greatest challenges (lowest scores) in the spatial hearing subtest. *B*, SSQ scores significantly decreased with increased error on stationary sound localization ($p = 0.009$); lines are fitted to data predicted from the lmer model. *C*, There was no effect of the poor slopes of sound movement perception on SSQ subtest scores ($p = 0.95$); lines are fitted to data predicted from the lmer model.

spatial hearing (lower scores) than speech (t_{312} = 9.05, p > 0.0001) or qualities of hearing (t_{312} = 12.92, p > 0.0001) in the early onset group and poorer self-reported spatial than qualities of hearing in the late onset group (t_{312} = 2.98, p = 0.036). Scores were similar between the groups ($F_{1,89}$ = 2.55, p = 0.11), but there was a trend for better spatial hearing reported in the late onset than early onset group (t_{122} = 2.87, p = 0.051). Figure 4B shows the SSQ scores plotted against error on the stationary sound localization task with CI on in the 8 (7 late onset and 1 early onset) children with data on both measures. Data plotted in Figure 4B show a significant decline in SSQ scores as sound localization error with the CI on increases [estimate (SE) = −0.11 (0.03)]. SSQ scores in each subtest are plotted against perception of sound movement direction, measured as slope of Gaussian curve, in Figure 4C. No significant effects of slope were found on SSQ scores [estimate (SE) = −0.32 (4.84)], likely reflecting mostly shallow slopes (i.e., poor perception of direction of moving sound) in this cohort.

DISCUSSION

Results indicate that CI use varied considerable in children with SSD and declined during the COVID-19 pandemic. In this unique group of children and adolescents with short duration SSD, the younger children gained more symmetric hearing than the older adolescents. The CI provided a slight improvement in localization of sounds on the side of the deaf ear, but spatial hearing remained poor with high error, localizing stationary sounds and limited perception of direction of moving sound.

Variable Acceptance of CI in Children/Adolescents with SSD

Consistency of CI use has signaled an early sign of potential benefits and device acceptance in children with SSD. As in earlier reports (31–33), the present cohort used their CIs consistently in the prepandemic period (~6 h daily on average) with only slight decreases over time; however, CI use dropped by ~1.5 hours during the pandemic (Fig. 1). This could reflect a decreased need for listening due to reduced social opportunities and less exposure to speech associated with school closures (37). Recent efforts are being made to provide additional support to promote more consistent CI use in some members of the cohort.

Children/Adolescents with SSD Show Improved Speech Perception with CI

The greatest benefits of CI in our cohort of children/adolescents with SSD were found in speech measures; they demonstrated speech understanding in the implanted ear and significant SRM (Fig. 2). Remarkably, young children with short durations of SSD achieved symmetric bilateral function, consistent with cortical development from the deaf ear with CI use in a similar cohort (18,38). Yet, older children with late onset SSD had persistently poorer hearing in their CI ear than their NH ear, reflecting an ongoing aural preference for the latter. Cortical responses suggest a deterioration of input to the brain from the deaf ear in the late onset group that is not avoided by CI use (18). These findings contrast from adults with postlingual onset of SSD who achieve benefits such as spatial hearing, improved hearing in noise, and tinnitus reduction (23,39,40). Potential differences could relate to the etiologies of SSD (although both adolescents and adults show high prevalence of infection/inflammation and trauma (40)), changes in developmental plasticity occurring during adolescence, and/or the very short duration of SSD in the present cohort.

Minimal Benefits in Sound Localization with CI

Although there was a slight benefit of CI use for localization of stationary sound on the side of the deaf ear, localization of static and moving sound remained poor with the CI (Fig. 3). This likely relates to poor access to binaural cues through bimodal hearing (20). Indeed, poor perception of moving sound direction has also been reported after CI in adults with SSD (23). Self-reported hearing challenges, particularly in spatial hearing, were predicted by the degree of error made in the stationary sound localization task (Fig. 4), which highlights the importance of binaural hearing. Efforts to better match input between the ears to support spatial hearing might improve these outcomes (20,22).

Study Limitations

The present prospective study presents data from a large cohort of children with SSD who received CIs (n = 57). Despite a clear protocol for inclusion and exclusion, some children became inconsistent CI users (as shown in Fig. 1) and did not return for the study testing. This highlights a potential bias in the outcome data toward more successful users. In addition, lockdowns and restrictions related to the COVID-19 pandemic may well have exacerbated challenges of CI use and ability of families to attend in-person follow-up appointments. Finally, many of the children were too young to complete behavioral testing so outcomes in these measures need to be monitored as the cohort grows and develops to assess whether present findings hold over a longer term.

Conclusions

Benefits of CI in children with limited durations of SSD are clearer for children receiving CIs at young ages than for older children/adolescents. Spatial hearing challenges remain despite slight improvements with CI use. Efforts to increase CI acceptance and consistent use are needed in children and adolescents with SSD.

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