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Child- and Environment-Related Factors Influencing Daily Cochlear Implant Use: A Datalog Study

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Objectives: To understand the varying levels of daily cochlear implant (CI) use in children, previous studies have investigated factors that may be of influence. The objective of this study was to investigate the degree with which new child-related and environment-related characteristics were associated with consistent CI use.

Design: The design of this study was retrospective. Data were reviewed of 81 children (51% females, mean age 6.4 years with a range of 1.3 to 17.7 years) who received a CI between 2012 and 2019. Developmental status, quantified burden of comorbidity, hearing experience, and hearing environment were investigated for correlation with consistency in daily CI use. The CIs datalog was used to objectively record the wearing times. Associations were examined using univariate correlation analyses and a linear regression analysis.

Results: On average, the CI was worn 8.6 hr per day and 59% of the children wore it more than 8 hr daily. The latter children's hearing performance was significantly higher than that of the others. Consistency in CI use correlated significantly with the child-related characteristics chronological age, nonverbal intelligence quotient (IQ), American Society of Anesthesiologists physical status class, pre CI acoustic experience, CI experience, and one of the environment related characteristics "parental communication mode." In a multivariate linear regression model, consistency in CI use was significantly dependent on nonverbal IQ and parental communication mode. These together accounted for 47% of the variation in daily CI use.

Conclusions: The findings indicate that children with lower nonverbal IQ scores and low exposure to oral communication by their parents are at risk of inconsistent CI use.

Key words: Children, Cochlear implant, Datalog, Device use, Hearing loss, Pediatric.

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INTRODUCTION

Cochlear implants (CIs) provide access to sound for hearing impaired children. These children's speech perception scores and speech production scores increase with more CI experience over the years and consistent CI use on a daily basis (Fryauf-Bertschy et al. 1997; Wie et al. 2007; Easwar et al. 2018).

Previously, daily use of hearing aids and CIs was often proxy reported through questionnaires with semantic scales (e.g., *none of the time*, …, *all the time*; Quittner & Steck 1991; Archbold et al. 2009). Marnane and Ching (2015) reported that parents often regard use exceeding 8 hr per day as "full-time," a threshold adopted by later studies (Easwar et al. 2016; Wiseman & Warner-Czyz 2018). In two more recent studies, nearly 90% of the parents reported that their children wore their hearing device (CI and hearing aid) for more than 8 hr per day (Contrera et al. 2014; Marnane & Ching 2015). There is reason to believe, however, that 90% is an overestimation: in a study by Walker et al. (2013), 84% of the parents were likely to overestimate the child's daily hearing aid use, with an excess of 2.6 hr on average. In that study, the investigators had objectively measured hearing aid use with a datalog feature that registered for how long per day the hearing aid was turned on. They concluded that 58% of the children used the hearing aid for more than 8 hr per day. Corresponding figures from other studies are 49% and 73% (Easwar et al. 2016; Wiseman & Warner-Czyz 2018). These findings indeed suggest that rates of fulltime hearing device use are substantially lower than 90%.

Many characteristics, either child-related or environment-related, have been associated with the children's CI use. In parent report studies, longer daily CI use was associated with the following characteristics: absence of additional disabilities (Marnane & Ching 2015), younger implantation age (Archbold et al. 2009; Contrera et al. 2014), more CI experience (Quittner & Steck 1991), better speech perception after implantation (Fryauf-Bertschy et al. 1997; Wie et al. 2007), higher maternal education (Marnane & Ching 2015), parents' trust in the beneficial effect of the CI (Wie et al. 2007), and the child's use of verbal communication rather than sign language (Quittner & Steck 1991; Archbold et al. 2009). Additionally, reasons given by children and parents for shorter daily CI use were poor hearing benefits (53%), social pressure (21%), and coil-offs (17%), that is, the accidental detachment of the CIs external transmission coil (Contrera et al. 2014).

Predictors on hearing aid use may also be of value on predicting CI use. Longer hearing aid use has been associated with higher socioeconomic status, higher maternal education, higher chronological age, and more severe hearing loss (Walker et al. 2013; Marnane & Ching 2015).

To date, two studies have examined factors that influence children's CI use, objectively measured with the datalog feature. This enabled the investigation of factors predicting the daily CI use, in addition to categorical trends (e.g., 0 to 2 hr versus >8 hr). Easwar et al. (2016) demonstrated an average daily CI use of 9.9 hr in 146 children, with 73% exceeding 8 hr per day. That study mainly explored auditory factors. Shorter CI wearing times were associated with a higher frequency of coil-offs, less CI experience, and less acoustic experience with hearing aids before implantation. Chronological age, sex, and the order and side of implantation did not emerge as significant predictors. The statistical model accounted for 27% of the variation in CI use. This suggests that there are additional sources of variance that, so far, have not been taken into account.

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Patient-related factors have been evaluated by Wiseman and Warner-Czyz (2018). They reported a daily CI use of 7.6 hr on average in 71 children, of whom 49% exceeded 8 hr. Higher levels of CI use were associated with higher chronological age, absence of comorbidity, higher maternal education, and implantation at higher age. In that study, a multivariate model was not applied; any confounders could therefore not be identified. Moreover, the predictive values of characteristics could not be compared.

In summary, the following factors have already been associated with consistency of CI use: comorbidity, chronological age, implantation age, CI experience, pre-CI acoustic experience, maternal education, and coil-offs. However, the overall predictability might be increased with the inclusion of additional factors. The dataset used in the present study permits examining environment-related characteristics such as bilingual parenting and parental communication mode, as well as other clinically relevant variables like developmental status and burden of comorbidity.

We therefore quantified child-related and environment-related characteristics (e.g., health and developmental status, appointment adherence, parental communication mode) and created a multivariate model to identify new associations, strengthen evidence, and investigate the interdependency of known predictors.

PARTICIPANTS AND METHODS

Participants and Data Selection

The participants in this study are of a group of 82 children who received a CI between 2012 and 2019 in the CI Center of the Sophia Children's Hospital of the Erasmus University Medical Center in Rotterdam, the Netherlands. The selected participants were between 15 months and 18 years of age. Participants received either a Cochlear CI (with an N6 or N7 sound processor) or an Advanced Bionics CI (with a Naida Q70 or Q90 sound processor). Twenty-eight children received a CI unilaterally and 53 bilaterally. In May 2019, the participants' files were reviewed for test results, surgery reports, therapist correspondence, consultation reports, and school reports. Only the most recent results of psychological examinations and CI performance evaluations were used in the analyses.

Variables and Data Collection

Daily CI Use • Information on daily CI use was obtained from the CIs datalog, which records the average time per day the CI processor is turned on and connected to the implant. The duration of the recordings ranged from 30 to 395 days. For sequentially implanted bilateral CIs, the datalog of the first implant was used for analysis. For simultaneously implanted bilateral CIs, the group difference between sides was not significant ($t(22) = -0.46$, $p = 0.65$; mean difference ± SD = 0.47 ± 0.54). Therefore, we used the mean of the wearing times of the left and right CI for analysis.

CI use was defined as "inadequate" if it was below 2 hr per day, "intermediate" between 2 and 8 hr, and "adequate" above 8 hr, as also used in other studies (Easwar et al. 2016; Wiseman & Warner-Czyz 2018).

Developmental Status • Chronological age and the nonverbal intelligence quotient (IQ) served as measures of the participants' development. Chronological age was measured on the last day of the datalog recording. Intelligence tests were routinely administered during the clinical follow-up by a psychologist, using either the Bayley Scales of Infant Development, the SON Intelligence Test, or WISC-III, dependent of age (Wechsler 1982; Bayley 1991; Tellegen & Laros 1993). These are standardized intelligence tests, adjusted for age.

Comorbidity • To quantify the participants' burden of comorbidity, we assessed the following variables: preterm birth, the sum of treating practitioners, and the American Society of Anesthesiologists (ASA) physical status class (Doyle & Garmon 2019). The latter was determined by an anesthesiologist, prior to implantation. It specifies the functional impairment participants may have from additional disabilities on a scale from 1 to 5 (i.e., healthy, …, moribund). The sum of practitioners who had treated the child at any point in time served as another way to assess comorbidity. Practitioners often involved in the treatment of additional disabilities were neurologists, ophthalmologists, and pediatricians.

Hearing Experience • CI experience and pre-CI acoustic experience were added to estimate the participants' hearing experience. A participant's pre-CI acoustic experience was calculated as time in years between the first hearing aid prescription and the first implantation.

Hearing Environment • Environmental characteristics gathered were bilingual parenting and parental communication mode. This information was reported by the children's parents in recurrent appointments with a speech therapist. Bilingual parenting was considered present when two or more different languages were spoken at home. Parental communication was classified into three categories: Oral communication, a combination of oral communication and sign language, and sign language solely.

Responsibility • We created a scoring model to evaluate appointment adherence and diligent use of the CI and merged it into one "responsibility" factor (see Appendix 1 in Supplemental Digital Content, http://links.lww.com/EANDH/A676). A higher score on the responsibility scale indicates less appointment adherence and less diligent CI care.

Hearing Performance • As many young children were included in the study, hearing response thresholds measured with free-field audiometry served as a measure of hearing performance. The hearing thresholds were measured at 0.5, 1, 2, and 4 kHz. For the purpose of analysis, we determined the mean of these four hearing thresholds for each of the three categories of CI use. For children with sequentially implanted CIs, the hearing thresholds of the first implant were used.

Statistical Analysis

For variable selection, continuous variables were analyzed for correlation with daily CI use with Spearman's rank-order test. Nonparametric tests were used to accommodate for non normally distributed data. Associations between dichotomous or categorical variables and CI use were analyzed using respectively the Mann–Whitney U test, a nonparametric version of an independent *t* test, and the Kruskal–Wallis test, a non parametric version of a one-way analysis of variance. To correct for family-wise error due to multiple comparisons, the Benjamini–Hochberg procedure was followed (Benjamini & Hochberg 1995).

TABLE 1. Summary data for sleep duration (hr/24 hr) across age bands and age category

Age Band or Category	Mean
0–2 mo	14.6
3 mo	13.6
6–12 mo	12.9
1–2 yrs	12.6
2–3 yrs	12.0
4–5 yrs	11.5
6 yrs	9.7
7 yrs	9.4
8 yrs	9.3
9 yrs	9.3
10 yrs	9.1
11 yrs	9.0
12 yrs	8.9

Data in this table were published by Galland et al. (2012).

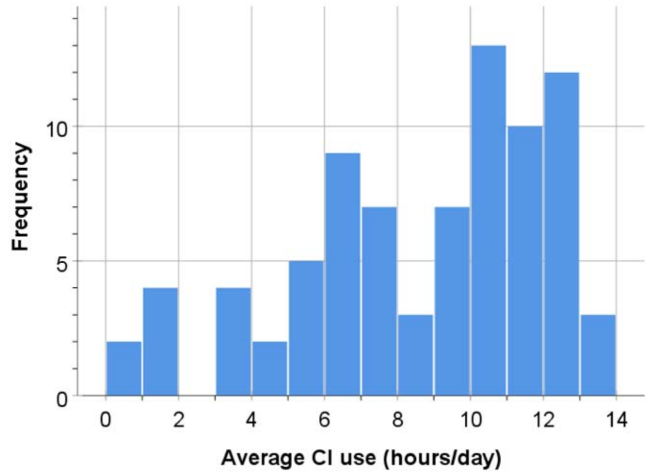

Fig. 1. Frequency of observed daily CI use. Histogram of daily CI use in 81 children, stratified by hour, plotted against the observed frequency. Class width = 1 hr per band. CI indicates cochlear inplant.

Adjustment for Time Asleep • Assuming that younger children sleep longer than older children do, younger children have fewer hours available to use the CI. We therefore needed to calculate a "CI use per hour awake ratio" for which we took the average sleep times per age category, published by Galland et al. (2012), see Table 1. The CI use per hour awake ratio was analyzed for univariate correlation with chronological age.

Regression Analysis • The variables significantly correlating with daily CI use were entered into a multivariable linear regression analysis. Missing data were handled with fully conditional specification as multiple imputation method (Van Buuren et al. 1999). Substituted data were based on all variables included in this study. The scatterplots after imputation showed an evenly dispersed array, which closed the gaps between the vast majority and outlying scores. An alpha level of 0.05 was set as the threshold for significance. All statistical analyses were performed in IBM SPSS Statistics 25.0.0.1. This study was conducted according to the principles of the Declaration of Helsinki (64th WMA, 2013) and the General Data Protection Regulation (Association, 2001; Schermer, Hagenauw, & Falot, n.d.).

RESULTS

Of the 82 initially selected participants, 1 was not available for reassessment due to family emigration. This resulted in the inclusion of 81 participants (40 males and 41 females) between the age of 1.3 and 17.7 years (mean ± SD = 6.4 ± 3.4). The mean time since implantation was 2.8 years (SD = 1.8). Table 2 displays the demographics.

Daily CI Use • The mean length of CI use was 8.6 hr per day (SD = 3.5, median = 9.2), with use exceeding 8 hr in 48 participants (59%). The CI use was intermediate (between 2 and 8 hr/day) in 27 children (33%) and inadequate (less than 2 hr/day) in 6 children (7%). See Figure 1 for the distribution of CI use.

TABLE 2. Demographics of the study population

Characteristic	M (SD)	n (%)
Age	6.4 (3.4)	81 (100)
Gestational age (wks)	38 (2.7)	64 (79)
Gender		
Male		40 (49)
Female		41 (51)
Nonverbal IQ	97.9 (19.6)	57 (70)

IQ indicates intelligence quotient; M, mean.

Descriptive Statistics • The IQ tests were taken at mean age 5.3 years (SD = 2.8), a mean 1.4 years (SD = 1.8) before the last datalog assessment. The longest interval was 6.6 years. The mean nonverbal IQ was 97.9 (SD = 19.6). IQ scores were missing in 24 cases, of which 4 concerned participants with CI use below 2 hr per day: 2 could not be tested for health reasons, 1 was too young, and 1 was uncooperative. Missingness of IQ scores was at random and was not associated with other independent variables. ASA classes ranged from 1 to 3. Forty-four children (54%) were classified as ASA class 1 (healthy), 32 children (40%) as ASA class 2 (systemic disease without functional limitations), and 5 children (6%) as ASA class 3 (systemic disease with severe invalidation). Types of severe invalidation included: Kniest syndrome (i.e., bone dysplasia), Down syndrome, and cardiac and pulmonary anomalies. The sum of treating practitioners ranged from 1 to 9. For 52 participants (64%), the otorhinolaryngologist was the only treating physician. Other clinicians often involved were neurologists, ophthalmologists, and pediatricians. (See Appendix 2 in Supplemental Digital Content, http://links.lww.com/EANDH/A698). The CI experience ranged from 1 month to 6.3 years (mean ± SD = 2.8 ± 1.8) and was <1 year in 17 children and <5 years in 69 children. The mean pre-CI acoustic experience was 3.3 ± 3.0 (mean ± SD) years. The parental communication mode was spoken for 56 participants (69%), sign language for 4 participants (5%), and a combination for 21 participants (26%). Characteristics across categories of CI use are displayed in Table 3.

Six variables correlated significantly with daily CI use: chronological age, nonverbal IQ, ASA class, pre-CI acoustic experience, CI experience, and parental communication mode, see Figure 2. The correlation matrix of all the used variables can be found in Appendix 3 in Supplemental Digital Content, http://links.lww.com/EANDH/A699.

Developmental Status • Chronological age (r_s = 0.45, p < 0.001) and nonverbal IQ (n = 57, r_s = 0.28, p = 0.04) were positively correlated with CI use. To adjust for younger children's longer sleep, we performed an analysis on CI use as a proportion of available hours; this did not show a significant

TABLE 3. Demographics and distribution of values across categories of CI use

Characteristic	Category of CI Use		
	0–2 hr/day	2–8 hr/day	8–14 hr/day
n (%)	6 (7.4%)	27 (33.3%)	48 (59.3%)
Age, M (SD)	5.73 (3.58)	5.13 (3.76)	7.25 (2.98)
Gestational age, M (SD)	36.80 (5.42)	38.80 (2.01)	38.01 (2.37)
Gender (female)	3 (50%)	14 (51.9%)	23 (47.9%)
Nonverbal IQ, M (SD)	50 (0.00)	95.60 (21.44)	101.20 (16.02)
Missing	4 (66.7%)	12 (44.4%)	8 (16.7%)
Bilingual parenting	3 (50%)	13 (48.2%)	12 (25%)
Missing		1 (3.7%)	1 (2.1%)
ASA class, M (SD)	2.17 (0.98)	1.59 (0.57)	1.40 (0.54)
Prelingual onset of deafness	3 (50%)	22 (81.5%)	20 (41.7%)
Missing	1 (16.7%)	2 (7.4%)	3 (6.3%)
Age at implantation, M (SD)	3.1 (1.92)	2.93 (3.44)	4.13 (2.82)
Implant side (right)	3 (50%)	2 (7.4%)	7 (14.6%)
Implant side (bilateral)	1 (16.7%)	19 (70.4%)	33 (68.8%)
Manufacturer CI (Cochlear)	3 (50%)	19 (70.4%)	33 (68.8%)
CI experience, M (SD)	2.62 (1.69)	2.23 (1.69)	3.19 (1.73)
Pre-CI acoustic experience, M (SD)	2.88 (1.99)	2.22 (2.81)	3.92 (3.06)
Missing		2 (7.41%)	2 (4.17%)
Oral parental communication mode	2 (33.3%)	11 (40.7%)	43 (89.6%)
Hearing threshold, M (SD)	50.9 (15.4)	37.0 (22.0)	24.3 (4.9)
Missing		1 (3.7%)	

Gender: male, ethnicity: non-Western, implant side: left, implant side: unilateral, manufacturer CI: Advanced Bionics are not listed in the table as they were used as reference conditions. Hearing threshold is the loudness (in decibel) required for the participant to notice sound.
ASA indicates American Society of Anesthesiologists physical status, measure for comorbidity; CI, cochlear implant; IQ, intelligence quotient; M, mean.

correlation with chronological age ($r_s = 0.20$, $p = 0.08$). Thus, the CI use per available hour was relatively stable across age.

Comorbidity • Preterm birth was not significantly associated with daily CI use ($r_s = -0.003$, $p = 0.98$). Daily CI use correlated significantly with the sum of treating practitioners ($r_s = .-0.24$, $p = 0.03$) but a Kruskal–Wallis test demonstrated no significant difference in CI use across the sum of treating practitioners χ^2 (8)= 14.72, $p = 0.07$). Therefore, the sum of treating practitioners was not entered in the regression model. Daily CI use correlated significantly with ASA class ($r_s = -0.30$, $p = 0.007$). Also, ASA class correlated significantly with the sum of practitioners ($r_s = 0.50$, $p < 0.001$). There was a significantly different distribution of daily CI use over different ASA classes (χ^2 (2)= 10.73, $p = 0.01$). The difference in daily CI use between ASA class 1 and ASA class 2 was not significant ($p = 0.14$). CI use in ASA class 3 was significantly lower than in ASA classes 1 or 2 ($p = 0.002$ and $p = 0.02$, respectively).

Hearing Experience • Pre-CI acoustic experience correlated significantly with daily CI use ($r_s = 0.37$, $p = 0.001$). CI experience did not correlate significantly with daily CI use ($r_s = 0.18$, $p = 0.11$). Still, because Easwar et al. (2016) did show a significant relation between CI experience and daily CI use, we entered CI experience in the regression model. Both pre-CI acoustic experience and CI experience were highly associated with chronological age ($r_s = 0.78$, $p < 0.001$ and $r_s = 0.40$, $p < 0.001$, respectively).

Hearing Environment • Bilingual parenting did not correlate significantly with daily CI use ($r_s = -0.22$, $p = 0.06$). Parental communication mode did correlate significantly with daily CI use ($r_s = -0.55$, $p < 0.001$) and also with ASA class ($r_s = 0.29$, $p = 0.01$), pre-CI acoustic experience ($r_s = -0.29$, $p = 0.01$), CI experience ($r_s = -0.23$, $p = 0.04$), and chronological age ($r_s = -0.40$, $p < 0.001$). CI use differed significantly across the parental communication modes (χ^2 (2) = 21.90, $p < 0.001$), see Figure 2. Oral parental communication mode was significantly associated with more daily CI use compared to a combination of oral and sign language and sign language solely ($p < 0.001$). CI use in the combined parental communication mode did not differ from that in the sign language group ($p = 0.68$).

Responsibility • The responsibility rating, which was based on appointment adherence and diligent CI care, did not correlate significantly with daily CI use ($r_s = 0.04$, $p = 0.074$).

Hearing Performance • Hearing thresholds of children in the "adequate" (>8 hr/day) CI use group differed significantly from those in the "intermediate" (2 to 8 hr/day) group and "inadequate" (<2 hr/day) group ($p = 0.001$ and $p < 0.001$, respectively). Since the direction of causality between CI use and hearing thresholds has not been clarified, we did not enter hearing thresholds into the regression analysis.

All correlations remained significant after correcting for multiple comparisons with the Benjamini–Hochberg procedure.

Regression Analysis

We noted 28 missing values: 24 IQ scores and data on pre-CI experience for 4 participants. Missing scores were complemented with multiple imputation. We performed a multivariate linear regression analysis on the dependency of CI use upon chronological age, nonverbal IQ, ASA class, CI experience, pre-CI acoustic experience, and parental mode of communication. Table 4 provides a summary of the predictors used in the analysis. Significantly associated with CI use were nonverbal IQ (B = 0.04, $p = 0.01$) and parental communication mode (B = -2.82 $p = 0.002$ for "combination" and B = -4.46, $p = 0.003$ for "sign language"). The R^2 value of .47 indicates that the model explained 47% of the variation in daily CI use. The model indicated that higher nonverbal IQ was associated with more CI

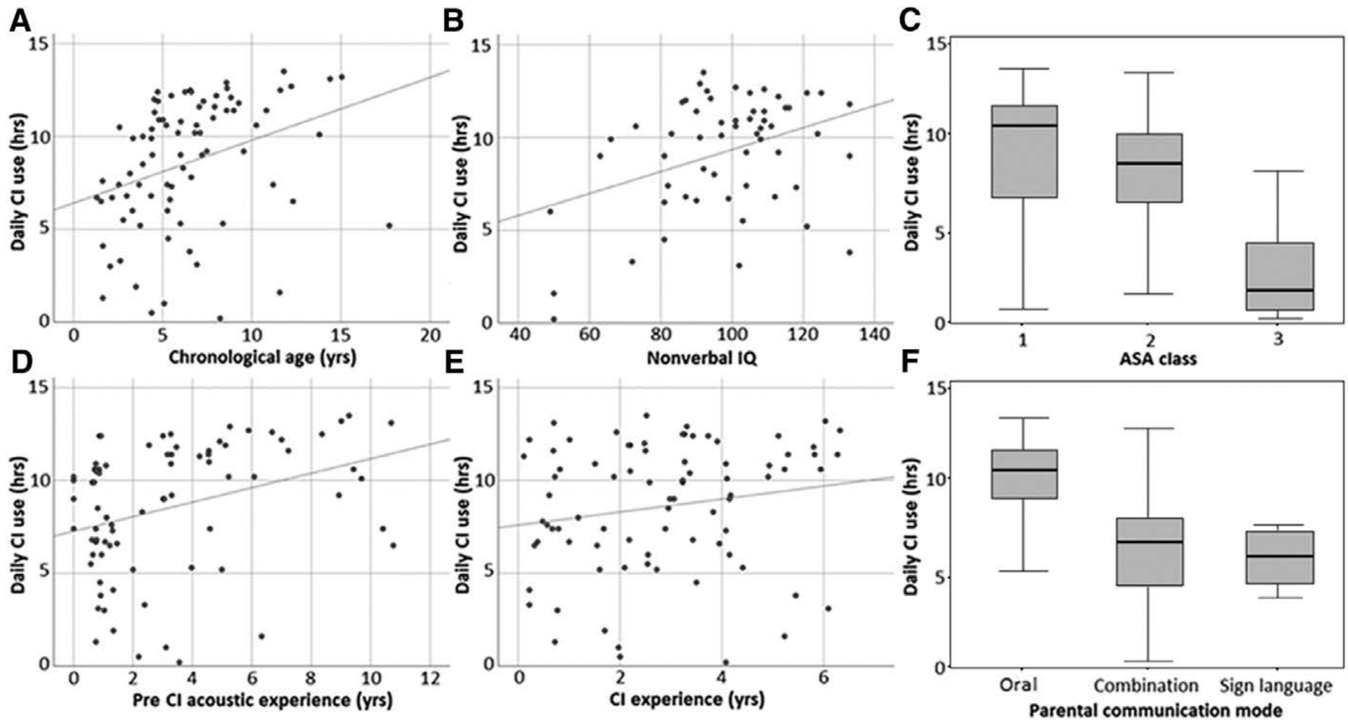

Fig. 2. Plots of CI use time against possible predictors. A, Chronological age (n = 81, r_s = 0.45, p < 0.001); B, Nonverbal IQ (n = 57, r_s = 0.28, p = 0.04); C, Boxplot of CI use time against ASA class (n = 81, p = 0.01); D, Pre-CI acoustic experience (n = 77, r_s = 0.37, p = 0.001); E, CI experience (n = 81, r_s = 0.18, p = 0.11); F, Boxplot of CI use time against parental communication mode (n = 80, p < 0.001). Boxes in (C) and (F) represent the median (thick horizontal line), lower and upper quartiles (end of boxes), minimum and maximum values (ends of whiskers). CI use did not significantly vary between ASA classes 1 and 2 (p = 0.42). CI use did not significantly vary between parental communication modes of combination and sign language (p = 1.00). ASA indicates American Society of Anesthesiologists; CI, cochlear inplant; IQ, intelligence quotient.

use. When oral parental communication mode was used as the reference condition, a combination of verbal and sign language and sign language solely both were associated with significantly less daily CI use. Chronological age, ASA class, CI experience, and pre-CI acoustic experience had no significant relation with daily CI use. Additionally, chronological age, CI experience, and pre-CI experience scored higher on collinearity (Variance Inflation Factor > 3.5).

Validity of Assumptions • Assumptions of the analysis were tested. Five outliers were detected, with standardized residuals of 2.30, -2.49, -2.35, -0.44, and -2.67, respectively. Omitting these cases improved the precision of the model with an increase in R^2 of 0.21. Significantly associated variables scored low on multicollinearity (Variance Inflation Factor < 1.5). The assumption of independent errors in regression was not violated (Durbin-Watson = 1.89). The scatterplot of standardized predicted values against standardized residuals showed an evenly dispersed array which suggests that the homoscedasticity assumption is met. The residuals were normally distributed (mean ± SD = 3.33E-16 ± 0.94).

TABLE 4. Summary of predictor estimates as a function of daily CI use

Factor	B	Std. Error	Beta	T	p	95% CIn	VIF
(Constant)	4.22	2.06	–	2.05	0.04	[0.11, 8.33]	–
Chronological age (log)	0.69	3.43	0.05	0.20	0.84	[–6.15, 7.53]	7.81
Nonverbal IQ	**0.04**	**0.02**	**0.25**	**2.56**	**0.01**	**[0.01, 0.07]**	**1.23**
ASA class 2	–0.54	0.66	–0.08	–0.82	0.42	[–1.84, 0.77]	1.11
ASA class 3	–2.59	1.48	–0.19	–1.75	0.09	[–5.54, 0.37]	1.48
CI experience	0.08	0.34	0.04	0.24	0.81	[–0.60, 0.76]	3.78
Pre-CI experience	0.13	0.26	0.12	0.52	0.60	[–0.38, 0.65]	6.42
Parental communication mode combination	**–2.82**	**0.86**	**–0.35**	**–3.28**	**0.002**	**[–4.55, –1.10]**	**1.47**
Parental communication mode sign language	**–4.46**	**1.44**	**–0.29**	**–3.11**	**0.003**	**[–7.33, –1.59]**	**1.13**

Regression coefficients from the multivariate linear regression analysis of 6 variables correlating with daily CI use in 81 subjects. Oral parental communication mode and ASA class 1 are not mentioned since they were used as the reference conditions. R^2 = 0.478. Bold print indicates significance.

ASA indicates American Society of Anesthesiologists physical status; B, unstandardized regression coefficient; CIn, confidence interval for B; CI, = cochlear implant; IQ, intelligence quotient; VIF, = Variance Inflation Factor; t, t statistic.

DISCUSSION

The goal of this study was to determine which, if any, child- and environment-related factors are associated with daily CI use. By means of a datalog feature in the CIs, wearing times were recorded objectively. In the population studied, the mean length of CI use was 8.56 ± 3.5 hr per day (mean ± SD), with 59% of the children using the CI for more than 8 hr per day. This percentage falls in the range of 49 to 73% reported by previous datalog studies (Easwar et al. 2016; Wiseman & Warner-Czyz 2018) and is comparable to the 58% found in a datalog study on children with hearing aids (Walker et al. 2015). It is considerably lower than the rates of nearly 90% reported by studies utilizing parent reports (Contrera et al. 2014; Marnane & Ching 2015), which highlights the value of objective measurement over subjective reporting (Walker et al. 2013). Intermediate use (between 2 and 8 hr) was seen in 33% of the children and inadequate use (<2 hr per day) in 7%. Inadequate levels were more frequent than the often reported nearly 3% rate in datalog and parent report studies (Ray et al. 2006; Archbold et al. 2009; Özdemir et al. 2013; Easwar et al. 2016). This difference may be explained by the small sizes of the low-performing groups and methodological differences (e.g., parent reports vs datalog). The 2- and 8-hr marks used to indicate inadequate and respectively adequate CI use may not be representative. These thresholds may be outdated and should be re-evaluated in future studies. In a large population-based study, children's mean CI use was between 8 and 12 hr per day. The quartile of children with the lowest amount of CI use utilized their CI 6.5 hr per day on average (Cristofari et al. 2017).

Higher nonverbal IQ and oral parental communication mode were significantly associated with higher levels of daily CI use. These predictors explained 47% of the variation in daily CI use.

Nonverbal IQ Correlates With Daily CI Use • Nonverbal IQ was taken as a measure of the participants' developmental state. In a previous study, consistency in CI use has been associated with two subsets of a nonverbal IQ test (Quittner & Steck 1991). The present study underlines the relation between longer daily CI use and a higher nonverbal IQ. There is a significant intercorrelation between IQ and the sum of practitioners. This suggests that lower IQ may reflect lower cognitive abilities as a result of comorbidity. An other explanation for the effect of IQ on CI use is that lower nonverbal IQ has been associated with lower speech recognition (Geers et al. 2003; Wie et al. 2007), which in turn is related to a decrease in daily CI use (Contrera et al. 2014). Considering the above, clinicians should realize that patients in lower IQ groups are at risk for inconsistent CI use. Higher levels of CI use might be achieved by frequent follow-up and support.

The Effect of Comorbidity on Daily CI Use • Previous studies have reported additional disabilities in 30% of children with sensorineural hearing loss (Fortnum et al. 2002; Birman et al. 2012). In the present study, 46% of the participants had an ASA class higher than 1. The difference in prevalence may be due to the inclusion of systemic diseases in ASA classes in the present study, other than the previously assessed neurodevelopmental disorders. By using ASA classes, the degree of comorbidity could be quantified in an empirical manner. The strong univariate correlation found is in line with the relation between longer CI use and a lower burden of comorbidities (Marnane & Ching 2015; Wiseman & Warner-Czyz 2018). Nevertheless, the results from our regression model do not support the evidence on the effect of comorbidity on CI use. The effect of ASA class may be partially confounded by parental communication mode. Our finding that children with a higher burden of comorbidity are likely to receive more sign language (whether or not combined with speech) underlines that multi-handicapped children may perform low on auditory domains (Birman et al. 2012). Every family handles the obstacles presented by multiple handicaps differently, which makes it difficult to predict how a patient will use the CI. For this reason, the use of a multidisciplined rehabilitation program is essential. Monitoring the development closely could be helpful to address problems and provide realistic expectations for all involved.

Parental Communication Mode Correlates With Daily CI Use • We examined the mode in which parents communicate with the participant as an environmental characteristic. While associations between CI use and the child's communication mode have been reported, the effect of parental communication mode had not yet been investigated so far (Quittner & Steck 1991; Archbold et al. 2009). In the present study, CI use was lower in children whose parents combined spoken language with sign language or used sign language solely. An explanation would be that little exposure to spoken language makes the CI redundant, and this effect may be magnified by lower auditory functioning as a result of low sound exposure (Tomblin et al. 2014, 2015). In another study, however, 53% of the participants attributed low CI use to poor subjective hearing benefits (Contrera et al. 2014). With inconsistent access to oral communication, children may come to prefer sign language, which their parents then may adopt. The lower-than-average levels of CI use seen when parents use a communication combination suggests a dose effect of sound exposure. More exposure to spoken language may help increase daily CI use. Recommended interventions are parent-child book reading and auditory-verbal therapy, the latter preferably for children with deaf parents (Ling 1993; Farrant & Zubrick 2013).

Chronological Age in Association With Daily Device Use • The correlation analysis revealed a high positive correlation between daily CI use and higher chronological age, like in other CI and hearing aid studies (Walker et al. 2013; Wiseman & Warner-Czyz 2018) and a large population-based study that reported CI use to increase between 0 and 6 years of age and reaching a plateau at 6 to 10 years of age (Cristofari et al. 2017). Possible explanations for this effect are that for younger children, wearing the CI may be complicated by headrests in seats and the CI may loosen with abrupt movements (Moeller et al. 2009; Walker et al. 2013). Correspondingly, the incidence of coil-offs reportedly declines with higher age (Easwar et al. 2016). Furthermore, infants tend to sleep more than older children, which results in less time available for wearing the CI. Our finding that CI use per available hour did not increase with higher age suggests that CI use is relatively stable across age, which was also reported by Easwar et al. (2016).

Generally, the CI experience increases with higher age and increased CI experience was found associated with higher daily CI use in previous studies (Quittner & Steck 1991; Sparreboom et al. 2011; Easwar et al. 2016). The latter finding was not corroborated in the present study, perhaps because the range of CI experience (0.1 to 6.3 years) was smaller than that in other studies (e.g., 0.0 to 15.3 years; Easwar et al. 2016).

Hearing Performance • Part of the unexplained variance in CI use we found may perhaps be attributed to the level of hearing performance. The significant difference in hearing thresholds between "intermediate" (2 to 8 hrs/day) CI use and "adequate" (>8 hrs/day) suggests such an association, though with unclear direction. The lesser use of a CI limits children's sound exposure, which negatively affects hearing abilities (Tomblin et al. 2015) while, conversely, poor hearing abilities may lead to less CI use (Contrera et al. 2014). Because this feedback mechanism is always present, we did not include the hearing performance in the regression analysis.

Limitations and Directions for Future Research • Several limitations of this study need to be addressed. First, the study sample is rather small. Studying a larger sample might have provided stronger evidence on low-performing children. Furthermore, the study population included predominantly children under 5 years of age. In a study in which all age groups are well represented, cross-group analysis could allow adjusting for age-dependent variables like CI experience.

Second, the retrospective nature of this study limits the data available for investigation. Only data on the most recent datalog period could be read. Thus, performance could not be followed over time, and the likelihood of the available data to be representative of the other datalog periods is unknown. The effects of CI experience and age on daily CI use could be more accurately examined by measuring changes in CI use over time. To further clarify the effect of age on CI use, the participants' time available for wearing the CI should be measured.

Third, the hospital of our study is a tertiary referral center. Children treated there often have a higher burden of comorbidity than children in the common population. This may be of influence on the generalizability of this study.

Fourth, IQ scores may vary over time and the proximity of the tests to the datalog assessment varies. This may have caused the reporting of weaker associations than they are in reality.

Fifth, the knowledge of a datalog feature may be an incentive to wear the device more often. Consequently, the incidence of adequate use we found may be higher than in the general CI wearing population.

CONCLUSION

The present study's findings add to the evidence that higher nonverbal IQ correlates with longer daily CI use. Daily CI use is also stimulated when a child's parents communicate orally. Previously found associations between chronological age or CI experience with daily CI use were not reaffirmed by this study.

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