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The Influence of Hearing Aids on the Speech and Language Development of Children With Hearing Loss

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Abstract

Importance—Hearing loss (HL) in children can be deleterious to their speech and language development. The standard of practice has been early provision of hearing aids (HAs) to moderate these effects; however, there have been few empirical studies evaluating the effectiveness of this practice on speech and language development among children with mild-to-severe HL.

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Objective—To investigate the contributions of aided hearing and duration of HA use to speech and language outcomes in children with mild-to-severe HL.

Design, Setting, and Participants—An observational cross-sectional design was used to examine the association of aided hearing levels and length of HA use with levels of speech and language outcomes. One hundred eighty 3- and 5-year-old children with HL were recruited through records of Universal Newborn Hearing Screening and referrals from clinical service providers in the general community in 6 US states.

Interventions—All but 4 children had been fitted with HAs, and measures of aided hearing and the duration of HA use were obtained.

Main outcomes and measures—Standardized measures of speech and language ability were obtained.

Results—Measures of the gain in hearing ability for speech provided by the HA were significantly correlated with levels of speech ($\rho_{179} = 0.20$; $P = .008$) and language: $\rho_{155} = 0.21$; $P = .01$) ability. These correlations were indicative of modest levels of association between aided hearing and speech and language outcomes. These benefits were found for children with mild and moderate-to-severe HL. In addition, the amount of benefit from aided hearing interacted with the duration of HA experience (Speech: $F_{4,161} = 4.98$; $P < .001$; Language: $F_{4,138} = 2.91$; $P < .02$). Longer duration of HA experience was most beneficial for children who had the best aided hearing.

Conclusions and Relevance—The degree of improved hearing provided by HAs was associated with better speech and language development in children. In addition, the duration of HA experience interacted with the aided hearing to influence outcomes. These results provide support for the provision of well-fitted HAs to children with HL. In particular, the findings support early HA fitting and HA provision to children with mild HL.

The development of effective communication skills is an essential accomplishment of early childhood. Poor communication abilities at the end of the preschool years have a cascading effect on social, academic, and later occupational success.[1,2] Thus, interventions that protect children from threats to poor speech and language development have important long-term effects on the quality of lives of those at risk for poor communication development.[3] Hearing loss (HL) during infancy and early childhood serves as a well-understood contributor to poor speech and language development by restricting a child's access to speech and language input. This limitation in access can range from minimal in children with mild HL to nearly complete in children with severe to profound HL, with accompanying deleterious effects on speech and language development. This has led to substantial efforts to implement Universal Newborn Hearing Screening programs to identify HL at birth or soon thereafter and to provide cochlear implants or hearing aids (HAs) along with speech and language intervention programs.

Although there have been numerous studies of the outcomes of children with HL over the past century, few have focused specifically on children who are hard of hearing (hereinafter, HH children; defined as those with better-ear pure-tone averages [PTAs] of 25-75 dB HL). Most research has grouped these children with those who have severe to profound HL. In contrast with the children with severe to profound HL, HH children are unlikely to use sign language or be considered for cochlear implantation; rather, it is assumed that they have the ability to acquire spoken language, particularly if provided with clinical intervention, including HAs and speech and language services. Davis et al[4] conducted the first investigation that focused on HH children. Subsequently, only a handful of additional studies have been published on the pediatric HH population. In general, these studies reported depressed speech and language achievement in the HH group as a whole when compared with age mates with normal hearing (NH); however, in some cases these children were similar to children with NH.[4-13] These studies were all conducted during a time when the standard of audiologic care for HH children included the fitting of HAs; however, none of these studies considered whether HA fitting and use influenced the speech and language outcomes of these children. It is possible that HAs provide benefit for these children's speech and language development, and, thus, some of the variability across studies is due to differential HA use in the study population.

The basic function of an HA is to amplify sound to levels well above the listener's threshold to maximize the amount of the speech spectrum that is available to the HA user; that is, to improve speech audibility. One of the intended effects of an HA in young children is to enhance speech and language development. Very recently, Stiles et al[14] were the first to report evidence that children's aided hearing was associated with HH children's language ability. If HA use does influence speech and language development, we would expect that early fitting and, thus, also longer HA use, would be associated with better speech and language development. However, Norbury et al[11] and Ching et al[13] have reported that the age at which children with HL received HAs was not associated with speech and language outcomes. Therefore, at this time, the information regarding the benefit of HA use on speech and language development in HH children is sparse and mixed.

The current study asked whether there is evidence that the audibility provided by HAs for children with mild-to-severe HL was associated with variation in speech and language outcomes in the preschool years. We also asked whether this benefit in aided hearing holds across levels of HL, as we might predict that children with mild HL have less need for aided hearing given their milder hearing loss. Finally, we asked whether there is an interaction between aided hearing audibility and length of HA use.

Methods

The present report is part of a multicenter, longitudinal study of Outcomes of Children with Hearing Loss conducted by investigators at Boys Town National Research Hospital, the University of Iowa, and the University of North Carolina–Chapel Hill. This study was approved by the internal review boards at these 3 cooperating research institutions. Parents provided written informed consent for their children's participation.

Participants

The children in this study were part of a larger cohort of children recruited at 6 months to 7 years of age who had bilateral HL from several Midwestern and central East Coast states. A description of the recruitment methods is provided in the Supplement. The current report focuses on 180 HH children in this cohort who were evaluated at ages 3 years (n = 74) and/or 5 years (n = 106) during the study period. Study inclusion criteria were (1) a bilateral HL (sensorineural, conductive, or mixed) with better-ear 3- or 4-frequency air conduction PTA (BEPTA) of 25 to 75 dB HL; however, children with HL related to transient etiology, such as otitis media with effusion, were excluded; (2) sufficient nonverbal cognitive, visual, and motor skills to perform the speech and language tests; (3) English spoken in the home by at least 1 primary caregiver; and (4) child use of spoken language. (See eMethods in Supplement for details of participant recruitment and testing.)

Measures

Audiologic Assessment—Air-conduction and bone-conduction thresholds at 500, 1000, 2000, and 4000 Hz were obtained. If a full audiogram could not be completed, the child's most recent unaided audiogram was obtained. The BEPTA was calculated from these audiograms. Middle ear status was measured in all children using tympanometry. Speech perception via live voice at conversational level was tested in the 3-year-olds using the Early Speech Perception Test, Standard Version.[15] For 5-year-olds, a recorded version of the Phonetically Balanced Kindergarten list,[16] presented at 65 dB SPL, was used.

Speech Intelligibility Index—The Speech Intelligibility Index (SII)[17] represents the amount of the speech signal that is available to a listener. The SII ranges from 0 to 1, where 0 indicates that none of the speech spectrum is audible and 1 indicates that all of the speech spectrum can be heard. In the present study, unaided SII values were computed based on the child's unaided pure-tone thresholds and an input of 65 dB sound pressure level (SPL). Similarly, aided SII values were computed using measures of the amplified signal provided by the HA at the ear drum with an input of 65 dB SPL. (See eMethods in Supplement for details of SII measurement, ear canal measurement, and HA fitting.)

Speech and Language Measures—Speech sound production at ages 3 and 5 years was measured with the Goldman-Fristoe Test of Articulation 2 (GFTA-2).[18] This measure provides an age-adjusted, norm-referenced score (mean [SD], 100 [15]) reflecting the child's ability to acceptably produce English consonants. Receptive and expressive language at age 3 years was measured using parental report from the Vineland Adaptive Behavior Scales (VABS)[19] and a direct assessment using the Comprehensive Assessment of Spoken Language (CASL).[20] Receptive and expressive language at age 5 years was measured using the Peabody Picture Vocabulary Test, Fourth Edition (PPVT-4)[21] and the Preschool Language Assessment Instrument, Second Edition (PLAI-2).[22] These are widely used measures of children's ability to understand and produce words and sentences. Although different measures of language were used at the 2 age levels, prior research has shown that measures such as these reflect a common single trait,[23] and therefore it should be possible to form a single common measure of language ability spanning the 2 age groups. Thus, we used a principal components analysis at each age level; consistent with findings in the prior literature we observed that all language subtests at each age loaded on a single language component.

At each age level, a Composite Language score was computed scaled in z-score units based on the norms for each test. Because the measures differed across the 2 age levels, we also needed to show that they were comparable. Fortunately, 33 children had been tested at both ages. Results showed that these children's Composite Language scores at ages 3 and 5 years were highly correlated ($\rho = 0.80$; n = 33; P < .001). Thus, we had evidence that language ability could be represented by a single Composite Language score regardless of the age level of the child. The use of Composite Language scores has the benefit of greater reliability owing to multiple measures and the elimination of multiple hypothesis tests based on correlated data. The Composite Language scores for the 33 children who participated at both age levels were included only in the 5-year-old group in the subsequent analyses. Also, because some children did not have the full complement of language measures in their age battery, no Composite Language score could be calculated for these children. This resulted in a loss of 25 children for the Composite Language measure.

Results

The demographic characteristics of the study participants are provided in Table 1 for the mild (26-45 dB HL) and moderate-to-severe (>45 dB HL) categories. Three children in the 5-year-old group had BEPTAs greater than 75 dB HL (76, 83, and 87 dB HL); however, in each case their BEPTA was below 76 dB HL prior to 5 years of age. All but 4 children had been fitted with HAs. For these children who did not wear HAs, aided SII was equal to unaided SII. With unpaired, 2-tailed t test, there were no significant differences between the mild and the moderate-to-severe groups with respect to their age at HA fitting: ($t_{165} = 1.34$; $P = .18$) or maternal education level ($\chi^2_4 = 1.18$; $P = .88$). Normal results for tympanograms in at least 1 ear or open pressure-equalizing tubes were found in 90% of the children. The rate of progressive HL, defined as a 10-dB difference between earliest and most recent BEPTA, was 12%, with 4% unknown owing to only 1 test.

Table 2 shows the speech sound production scores, according to unaided hearing level. At each age level, the measure of speech sound production (GFTA-2) showed the children with mild HL to have, on average, better speech skills than the children with moderate-to-severe HL. When the 2 age groups were combined, children with mild HL had a mean (SD) score of 95.36 (15.01) on the GFTA-2, whereas the moderate-to-severe group averaged 86.60 (18.04). This difference was significant ($t_{178} = 3.45$; $P < .001$). The mean (SD) score for children with NH is expected to be 100 (15). Thus, the children with moderate-to-severe HL were on average 1 SD below that of children with NH.

Table 2 also contains a summary of the individual language scores and composite scores grouped by level of HL and age group. When the composite scores were combined over the age groups, children with mild HL had a mean (SD) score of 0.26 (0.87), whereas children with moderate-to-severe HL had an average score of −0.08 (0.97). This difference was significant ($t_{154} = 2.23$; $P = .03$). Recall that these mean values are in *z*-score units, and. thus. the overall language performance of these children is similar to that expected for children with NH.

The results described herein demonstrate that the degree of unaided hearing based on the BEPTA is associated with speech and language development. However, most of these children spend at least a portion of their waking hours wearing HAs, which we hypothesized would result in improved speech and language above and beyond their unaided hearing. Thus, it was necessary to compute a measure of the degree to which each child's hearing was improved by HAs beyond their unaided hearing. The degree to which HAs can provide improved SII is constrained by the severity of the HL. Figure 1 shows the unaided and aided SII. As shown in Figure 1, both aided and unaided SII among the children in this study were associated with unaided PTA. Furthermore, aided and unaided SII were also correlated (r = 0.66; n = 167 children; P < .001). Thus, it was necessary to control for each child's unaided SII in order to examine the unique effect of aided hearing. We accomplished this by removing the variance of unaided SII that was shared with aided SII using a linear regression method and as a result created a residual aided SII (rSII) that was independent of unaided SII. Specifically, using a piece-wise regression method we found that the relationship between aided and unaided SII was nonlinear and was better modeled by 2 linear functions: 1 below an unaided SII of 0.16 and 1 above this cut point. Thus, to test for the unique effects of aided hearing, we created rSII scores by regressing children's unaided SII onto their aided SII, using 1 of 2 linear functions: 1 for children with unaided SIIs at or above 0.16 and 1 for those below 0.16. The residual variance produced by these regressions formed the rSII and was used to reflect the audible hearing provided by the HA independent of unaided hearing (see Supplement for method details).

Association of Aided SII With Improved Speech and Language Development

We tested the association of rSII with speech and language by correlating it with the GFTA-2 and the Composite Language scores obtained at either 3 or 5 years of age. Because the data were not normally distributed, a Spearman rank order correlation (Spearman ρ) was used. The correlation of rSII with GFTA-2 was significant (ρ_{179} = 0.20; P = .008). The correlation of rSII with the Composite Language was significant (ρ_{155} = 0.21; P = .01). Thus, the audibility provided by HAs to preschool children with HL is significantly associated with their speech and language development.

Benefits From Aided SII for Mild and Moderate-to-Severe HL

The analysis described herein tested the effects of aided SII across the whole group of children with HL. The data in Table 2 show that the speech and language outcomes of children with mild HL were generally better than those of children with moderate-to-severe HL. Thus, we examined whether the effect of rSII on speech and language differed between the mild vs moderate-to-severe groups. In this case, we used a general linear model to test whether the degree of HL (mild vs moderate to severe) interacted with the association of rSII with GFTA-2 and Composite Language. Figure 2 shows the linear relationships of GFTA-2 and Composite Language and rSII for the 2 groups. As can be seen in Figure 2, for both measures, the slopes were similar, and the results of a test for an interaction were not significant (Composite Language $F_{1,\,151}$ = 0.01; P = .90; GFTA-2 $F_{1,\,175}$ = 1.05; P = .31). Therefore, aided audibility had a similar relationship with speech and language development for children with mild and moderate-to-severe HL.

Benefits From Aided SII With Longer HA Use

The findings described in the previous subsection showed that the improved audibility provided by HAs is associated with improved development of speech and language and that this effect is seen across the range of HL from mild to severe. Thus, variation in the magnitude of rSII can be viewed as 1 form of dose. This dose can also vary over time based on the length of time the child has been wearing HAs. Furthermore, this duration effect can be expected to interact with the rSII dose.

To test this hypothesis, we asked whether speech and language outcomes were associated with length of HA use and, more specifically, whether length of use interacted with rSII. Because the relationships of length of HA use with speech and language outcomes were not linear, we partitioned length of HA use into 4 quartile bins. In this analysis, we also controlled for mother's educational level because this variable was weakly associated with the age at which the children received HAs and was moderately associated with speech and language development. We also controlled for the age of the child at testing to adjust length of use for the child's age. We conducted a general linear model wherein the language composite and GFTA-2 measures were associated with the number of months of HA use and the interaction of months of HA use and aided rSII, while controlling for mother's educational level and child's age at testing.

This model showed that the interaction of aided rSII and length of HA use was significant for both GFTA-2 ($F_{4, 161} = 4.98$; $P < .001$) and language ($F_{4, 138} = 2.91$; $P < .02$). The main effect of length of HA use was not significant for either speech or language. Table 3 shows the linear association between aided rSII and GFTA-2 and Composite Language for each quartile of length of use. For both GFTA-2 and Composite Language, the children in the highest quartile of use showed significant associations between aided rSII and both speech and language, whereas the children in the 2 lowest quartiles of use showed weaker and nonsignificant associations. These data then support the hypothesis that longer use of HAs in children provides the greatest benefit from aided hearing on speech and language development. The fact that the β coefficients shown in Table 3 were all positive indicates that greater length of use in combination with higher rSII values are associated with better speech and language outcomes, that is, that length of use and rSII have a multiplicative relationship with speech and language outcomes.

Discussion

Principal Findings

Hearing loss compromises one's ability to understand spoken language, but HL in children has the added effect of limiting children's ability to learn speech and language. This effect of HL on speech and language development has been shown in several studies.[4-8,10-12] In children, HAs should moderate the effect of HL on speech and language development. Currently, HA fitting is a part of the standard of care for children with HL; however, there has been little empirical evidence demonstrating whether improved hearing provided by HAs is associated with improved speech and language development for children who are HH. Thus, we hypothesized that improved audibility provided by the HA use would provide children with greater opportunities to successfully perceive and thus learn the speech and language patterns of their community. This prediction was supported by the findings that the degree of HA benefit, as measured by aided SII after adjusting for the unaided hearing (rSII), was associated with variations in speech and language abilities. The strength of these associations approached moderate levels. We would contend that even these modest effects are likely to have important long-term cumulative effects owing to the importance of language abilities during the school years.

Given that children with mild HL have more usable unaided hearing than children with moderately severe HL, we might expect that the benefits of HAs would be less for these children. This conjecture, however, was not supported in this sample. The benefits from HAs were similar for children with mild and moderate-to-severe degrees of HL. This may be due to the fact that HAs can usually provide children with mild HL with high levels of audibility, whereas they tend to provide more modest audibility for children with severe HL. However, for children with greater degrees of HL, the amount of gain, albeit limited in some cases, provides audibility that is not available without the HA.

If HAs provide benefit for speech and language development, we expected that this would also be reflected in the length of time the child had been fitted with the HA. This prediction was recently questioned by findings that children with mild-to-severe HL did not differ in speech and language development according to when they received their HAs.[11,13] Indeed, our data also showed that the simple main effect of length of HA use was not associated with speech or language outcome; however, when length of HA use and rSII were examined jointly, we saw that, among children with longer HA use, audibility provided by the HA became more reliably associated with better outcomes. We should note that in this study, the length of HA use is confounded with the age of initial HA fitting. Thus, these benefits may be due to either the length of use or the early receipt of HAs.

Implications for Clinical Management of Pediatric HL

Numerous studies have shown that speech and language development during the preschool years plays a vital role in the success of children in school and later life. This study shows that early provision of HAs to children with mild to severe HL is likely to result in better speech and language development, particularly when the child receives good audibility from HAs and has had a longer opportunity to wear the HA. Hence, early HA fitting is supported. This study showed that that these benefits extend to children with mild HL. Many of these children are not likely to be identified and fitted with HAs. These data would suggest that research should systematically examine the degree to which these children's speech and language is negatively influenced by this lack of HA provision and use. Finally, we should acknowledge that the degree of audibility will be determined, in part, by the quality of the HA fit within the constraints of the HL.

Conclusions

This study underscores the importance of not only providing HAs to children, but also insuring that HAs provide an optimal level of audibility.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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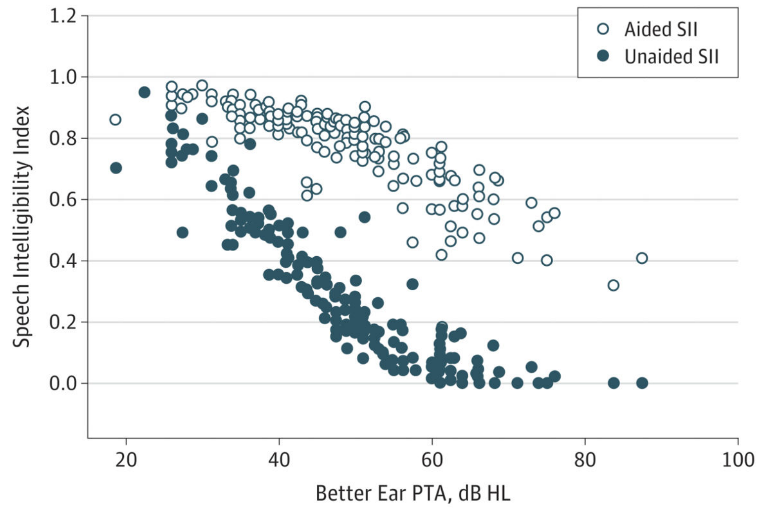

Figure 1. Participants' Speech Intelligibility Index (SII) as a Function of Unaided, Better-Ear 4-Frequency Pure-Tone Average (PTA)

Unaided SII (filled circles) and aided SII (open circles) for all research participants as a function of their unaided better-ear 4-frequency PTA. HL indicates hearing loss.

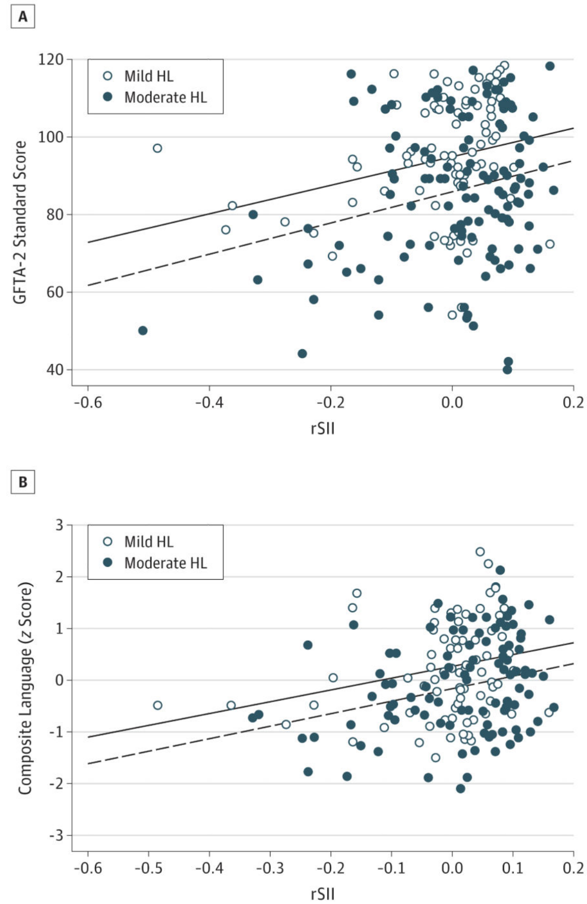

Figure 2. The Relationship Between Residualized Speech Intelligibility Index (rSII) and Speech and Language Achievement

A, The linear relationship between rSII and speech sound production ability (Goldman-Fristoe Test of Articulation 2 [GFTA-2]). B, Language ability for children with mild or moderate-to-severe hearing loss (HL). The rSII is a measure of the aided SII with unaided SII partialled out. Solid lines indicate mild HL; dashed lines indicate moderate-to-severe HL.

Table 1
Characteristics of Children With Mild and Moderate-to-Severe Hearing Loss (HL)

Characteristic	**Mild HL (PTA = 25-45 dB)**	**Moderate-to-Severe HL (PTA>45 dB)**
Children, No.	76	104
Males, %	55	51
Age at test, mean (SD), mo	51.48 (12.20)	50.88 (11.84)
Mother's educational level, %		
<High school	4	6
High school	14	13
Postsecondary	30	32
Bachelor's degree	29	23
Post bachelor's degree	22	26
HA users	74	102
Speech perception		
ESP, at 3 y, raw score	22.03 (5.17)	19.53 (7.79)
PBK at 5 y, %	82.00 (13.60)	75.46 (18.58)
Age at HA fitting, mean (SD), mo	17.20 (18.29)	13.41 (14.66)
Duration of HA use, mean (SD), mo	34.52 (18.09)	37.51 (15.91)

Abbreviations: ESP, Early Speech Perception Test; HA, hearing aid; PBK, Phonetically Balanced Kindergarten list; PTA, pure-tone average.

Table 2

Measures of Language and Speech at Either 3 or 5 Years of Age and Language and Speech for the Combined Age Groups[a]

Domain	Test	Mild HL	Moderate-to-Severe HL
Age Level, 3 y			
Language	CASL Basic	100.70 (14.1) (n = 30)	93.07 (22.21) (n = 42)
	CASL Syntax	90.84 (12.65) (n = 30)	84.48 (13.89) (n = 40)
	CASL Pragmatics	96.23 (14.44) (n = 30)	90.18 (16.98) (n = 40)
	VABS Communication	99.50 (12.82) (n = 22)	94.72 (15.17) (n = 37)
	Composite Language score	0.22 (0.89) (n = 45)	−0.15 (0.94) (n = 27)
Speech	GFTA-2	93.00 (12.97) (n = 30)	83.20 (19.04) (n = 44)
Age Level, 5 y			
Language	PPVT-4	104.60 (15.14) (n = 45)	97.78 (16.22) (n = 58)
	PLAI Receptive	10.76 (3.08) (n = 46)	9.65 (2.95) (n = 57)
	PLAI Expressive	10.91 (3.63) (n = 46)	9.47 (2.95) (n = 57)
	Composite score	0.22 (0.89) (n = 45)	−0.15 (0.93) (n = 55)
Speech	GFTA-2	96.91 (16.15) (n = 46)	89.10 (17.0) (n = 60)

Abbreviations: CASL, Comprehensive Assessment of Spoken Language; GFTA, Goldman-Fristoe Test of Articulation 2; HL, hearing loss; PLAI-2, Preschool Language Assessment Instrument, Second Edition; PPVT-4, Peabody Picture Vocabulary Test, Fourth Edition; VABS, Vineland Adaptive Behavior Scales.

[a]Data are given as mean (SD) with sample sizes.

Table 3

Linear Slope Values (β) for Composite Language and GFTA-2 With Aided Speech Intelligibility Index (SII) Adjusted for Unaided Residualized SII at 4 Quartiles of Duration of Hearing Aid Use

Quartiles of HA Use (mo)	Patients, No.	Outcome	β	*t*	*P* Value
Shortest (0-27)	39	Language	2.48	1.51	.13
		GFTA-2	53.76	1.86	.06
Second (28-34)	45	Language	1.16	0.78	.43
		GFTA-2	34.25	1.77	.08
Third (33-54)	44	Language	3.71	1.54	.12
		GFTA-2	119.60	3.02	.003
Longest (>54)	47	Language	3.92	2.49	.01
		GFTA-2	55.68	1.98	.04

Abbreviations: GFTA-2, Goldman-Fristoe Test of Articulation 2; HA, hearing aid.