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Language Outcomes in Young Children with Mild to Severe Hearing Loss

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Abstract

Objectives—This study examined the language outcomes of children with mild to severe hearing loss during the preschool years. The longitudinal design was leveraged to test whether language growth trajectories were associated with degree of hearing loss and whether aided hearing influenced language growth in a systematic manner. The study also explored the influence of the timing of hearing aid fitting and extent of use on children's language growth. Finally, the study tested the hypothesis that morphosyntax may be at particular risk due to the demands it places on the processing of fine details in the linguistic input.

Design—The full cohort of children in this study was comprised of 290 children were hard of 34 hearing (CHH) and 112 children with normal hearing (CNH) who participated in the Outcomes 35 of Children with Hearing Loss (OCHL) study between the ages of 2 and 6 years. CHH had a mean better ear pure tone average of 47.66 dB HL (*SD* = 13.35). All children received a comprehensive battery of language measures at annual intervals, including standardized tests, parent report measures, and spontaneous and elicited language samples. Principal components analysis supported the use of a single composite language score for each of the age levels (2, 3, 4, 5, 6 years). Measures of unaided (better ear pure tone average, Speech Intelligibility Index) and aided (residualized Speech Intelligibility Index) hearing were collected, along with parent report measures of daily hearing aid use time. Mixed modeling procedures were applied to examine the rate of change (227 CHH; 94 CNH) in language ability over time in relation to 1) degree of hearing loss, 2) aided hearing, 3) age of hearing aid fit and duration of use, and 4) daily hearing aid use. Principal components analysis was also employed to examine factor loadings from spontaneous language samples and to test their correspondence with standardized measures. Multiple regression analysis was used to test for differential effects of hearing loss on morphosyntax and lexical development.

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See Supplemental Digital Content, Appendix A List of Acronyms used throughout Outcomes in Children with Hearing Loss Study.

Results—Children with mild to severe hearing loss, on average, showed depressed language levels compared to peers with normal hearing who were matched on age and socioeconomic status. The degree to which CHH fell behind increased with greater severity of hearing loss. The amount of improved audibility with hearing aids was associated with differential rates of language growth; better audibility was associated with faster rates of language growth in the preschool years. Children fit early with hearing aids had better early language achievement than children fit later. However, children who were fit after 18 months of age improved in their language abilities as a function of the amount of hearing aid use. These results suggest that the language learning system remains open to experience provided by improved access to linguistic experience. Performance in the domain of morphosyntax was found to be more delayed in CHH than their semantic abilities.

Conclusion—The data obtained in this study largely support the predictions, suggesting that mild to severe hearing loss places children at risk for delays in language development. Risks are moderated by the provision of early and consistent access to well-fit hearing aids that provide optimized audibility.

INTRODUCTION

Early and consistent access to speech is regarded as important if not essential for successful speech and language development. In the introduction to this issue, we argued that mild to severe hearing loss (HL) in very young children may have an impact on oral communication development by restricting access to speech and language input (Introduction, Moeller and Tomblin, this issue, pp.xxx). Unlike children with severe and profound loss, these children do have some access to speech. However, this access will be highly dependent on the amplitude and spectrum of the speech signal, hearing aid (HA) characteristics and use, and the presence of noise. If this hypothesis is correct, it has obvious clinical importance. However, this viewpoint also has important theoretical implications.

In the Introduction, we noted that some traditional accounts of language acquisition placed limited importance on language input for language acquisition (Introduction, Moeller and Tomblin, this issue, pp.xxx). However, we noted that several prominent theoretical accounts of language development in recent years have expressed an alternative view. Specifically, these accounts emphasized that the child's access to language both in terms of quantity and quality does matter for language learning.

At a fundamental level, we are interested in identifying the degree to which spoken language acquisition is vulnerable to the challenges of mild to severe HL. This account predicts that any factor that constrains the child's access to language input will reduce the learning efficiency of the child. Due to their HL, children who are hard of hearing (CHH) are less likely to have successful uptake of the many sources of language information provided to them in their environment. In this sense, we can hypothesize that the language learning system is vulnerable to constraints on the availability of cues. Early and effective interventions that improve the access to these cues should mitigate the challenges of HL.

The viewpoint above makes sense if there is no limiting factor on the effects on input on language learning. It is possible, however, that language input saturates the language learning system at relatively low levels. In this case only a minimum amount of information is necessary for successful language development and a robust language acquisition or learning system does not require extensive "feeding" from the input. Within this robust learning system, mild to severe HL could still provide access to a sufficient amount of information for language learning to proceed. Clearly, profound HL eliminates so much speech information that it is not surprising that children with such losses will have very limited oral speech and spoken language development in the absence of amplification. Children with cochlear implants show rather good speech and language development in spite of the fact that these devices provide a degraded acoustic perceptual product. This fact supports the robust model of language learning. If the robust model holds, we should expect that CHH would often show normal levels of language development.

Outcomes of children who are hard of hearing

Although there have been numerous studies of the outcomes of children with HL over the past century, few of these have focused specifically on children with mild to severe HL. Instead, many of these studies merged children with mild and moderate losses with children who had severe and profound losses. As a result, such studies cannot be interpreted with respect to whether speech, language, and other important outcomes such as reading are influenced by milder degrees of HL.

In reference to CHH, Davis and her colleagues (1986) coined the term "our forgotten children" to highlight the dearth of research on children with mild to severe HL. Davis and colleagues conducted the first large-scale investigations of children with HL in the mild-to-severe range (Davis et al. 1981; Davis et al. 1986; Elfenbein et al. 1994). These studies reported depressed vocabulary and grammatical abilities in these school-age CHH. These findings, however, were challenged soon afterwards by studies showing little or no effect of mild to moderate HL on language (Sikora & Plapinger 1994; Wolgemuth et al. 1998; Briscoe et al. 2001; Norbury et al. 2001). In several of these studies, a subgroup of children with HL did show depressed skills, particularly with regard to phonological skills (Gilbertson & Kamhi 1995; Briscoe et al. 2001; Norbury et al. 2001). Authors of these studies acknowledged that small sample sizes resulted in limited statistical power to find group differences between CHH and their hearing peers. Furthermore, the wide variability in outcomes among CHH in some of these studies limits the reliance on group performance to interpret the results.

In the last 10 years, there has been a surge in interest in children with mild to severe HL. Wake and colleagues (2005) reported on the speech, language, and reading outcomes of young school-age children with mild through severe HL. Achievement levels of these children were between one and two standard deviations below the mean for hearing controls. More recently, Ching and colleagues (Ching et al. 2010; Ching et al. 2013; Ching & Dillon 2013) examined 3-year-old CHH who either wore HAs or cochlear implants. These authors found that among the HA users, communication outcomes were better for those with milder HL. Delage and Tuller (2007) reported depressed language skills in adolescents with mild and moderate HL. Complementing these studies were findings that children with HL were less adept at learning novel words (Gilbertson & Kamhi 1995). In contrast Fitzpatrick and colleagues (2011) found language abilities in children with moderate to severe losses were comparable to CNH. Thus, in the last 20 years, the evidence regarding language development in children with HL in the mild–to-severe range has been mixed at best.

A possible contributor to these mixed results may have to do with the fact that in all of these studies information about HA fitting or use among these children was not considered. In several studies the children were described as wearing HAs, but no information was included about the level of aided hearing provided by these devices. Therefore, it is unclear across these studies when these children were fit with HAs, if the HAs were set appropriately, and how consistently the HAs were used on a daily basis. One exception to this is a recent report by Stiles, Bentler, and McGregor (2012) in which school-age children's aided audibility (as represented by the Speech Intelligibility Index; SII) was a stronger predictor of word repetition, nonword repetition, and receptive vocabulary than BEPTA, suggesting that SII provides a more representative estimate of the functional hearing abilities of school-age children utilizing HAs.

A prominent feature of this literature is that none of these studies were longitudinal. If language development does depend on the recovery of statistical properties of the input and HL limits the child's access to this information, we might expect to see that the effect of HL and in particular improved audibility via HAs will be reflected in differences in language growth over development. In order to answer this question, longitudinal data obtained during the preschool years would be best.

Aims of the Current Study

The current manuscript examines the language outcomes of children with mild to severe HL during the preschool years. Study 1 will make use of our longitudinal design to explore the relationships between hearing level and language development where the measures of language were drawn from standardized tests. Within Study 1, we will compare the language growth of CHH with a control group of children with normal hearing (CNH). Next, we will examine the effects of HAs on the language development of CHH. Specifically, we examine whether: 1) the benefit of aided hearing, 2) the timing of HA fitting and the duration of HA experience across time, and 3) the amount of daily HA use, influences the language development of CHH. Study 2 will investigate whether the findings regarding hearing status and language as measured with standardized tests also hold for language measures from spontaneous samples. Finally, in Study 3, we ask whether there are differential effects of HL on morphosyntax, an aspect of language that depends on fidelity of phonetic perception, and vocabulary, an aspect of language that may not depend as heavily on fidelity of phonetic perception.

Study 1: Longitudinal analysis of language development in children with normal hearing and children who are hard of hearing

METHOD

Participants—As described in the General Methods article of this monograph, the Outcomes of Children with Hearing Loss (OCHL) study used an accelerated longitudinal design to follow children through the preschool years and into the early school years (see General Methods, Tomblin et al. this issue, pp.xxx). In this report, we will focus on the language status of the children from 2 through 6 years of age. As shown in the Appendix of the General Methods description language measures were obtained from 12 months of age to 9 years of age (Tomblin et al., this issue, pp. XXX). However, the language measures prior to the age of 2 and after the age of 6 were less extensive. In the General Methods, Table 3 shows that the number of children examined is greatest from age 2 through 6; thus, our analysis focused on language growth from age 2 through 6 years (Tomblin et al., this issue, pp. xxx). During this period of time 414 children (302 CHH, 112 CNH) participated. Of these children, 85 were seen once, 137 were seen twice and 192 were seen for three or more waves of assessment. Table 3 in the current article shows the number of children who participated at each assessment wave. The average BEPTA for CHH was 48.88 dB HL (*SD* = 14.13). All but one child in the CHH group wore HAs. Figure 1 shows their better ear aided SII values as a function of their average BEPTA. We should note that, as discussed in the General Methods, a small number of children with BEPTAs greater than 75 at the time of enrollment were included in the study after audiologists on the research team concluded based on results from objective measures that the behavioral thresholds were suprathreshold, Additionally, after enrollment some children's HL progressed beyond 75dB.

Unaided Hearing Status: As we noted in the introduction, under the model of learning vulnerability, the child's hearing status is hypothesized to play an important role in the child's speech and language development. Within this project, we have viewed hearing status as a complex variable in that most of the children in this study were wearing HAs. Thus, CHH can be thought of having two levels of hearing: their unaided hearing and their aided hearing. Unaided hearing was represented by the child's four frequency BEPTA. For most children, the BEPTA was similar across the period of study; therefore, the child's BEPTA was averaged across the observation intervals.

Aided Hearing Status: Residualized SII: The level of aided hearing can be represented by the aided SII. Aided SII represents the amount of the speech spectrum that is available to the child when amplification is worn. Figure 1 shows that better ear aided SII is strongly correlated with unaided BEPTA. In Tomblin et al. (2014b) we showed that a measure of SII that was independent of unaided hearing could be computed by regressing unaided SII onto aided SII which yields a residualized SII (rSII). In this study, we used the same method wherein we performed separate linear regressions for children with unaided SIIs below .16 and those with unaided SIIs above .16. This was necessitated by the fact that the relationship between unaided and aided SII was nonlinear and piecewise regression showed that two linear functions with a joint at .16 significantly improved the fit to the data. The resulting rSII measure can be thought of as a normalized HA gain measure where the magnitude of the gain is relative to the gain obtained by children with similar unaided hearing.

Length of hearing aid use: At the time of enrollment, parents of CHH were asked about the child's history of hearing services including the age of initial HA fitting. For those CHH who had not been fitted at the time of enrollment, this information was updated at subsequent visits. Thus, the length of HA use was computed as the difference between the child's age at any wave of testing and the child's age at HA fit. We acknowledge that this does not take into account periods between fitting and a testing wave when the child was not wearing the HAs.

Daily hearing aid use: As just noted, HA use after fitting can be variable within a day and over days. Data concerning daily HA use were obtained via a parent questionnaire (see Walker et al. this issue, pp. XXX and Walker et al. 2013). Using this questionnaire, parent-report data concerning hours of HA use during the week and the weekend were obtained at each wave of data collection. In the current study, we computed an estimate of daily HA use by combining the weekend and weekday reports. Walker et al. has found that relative HA use was stable across time, thus for the analysis of HA use, we averaged across the observation waves for each child (see Walker, this issue, pp. XXX). This variable was negatively skewed, therefore for later analysis purposes we created categories of HA use (<10 hours/day, n = 52; 10–11.49 hours/day, n = 51; 11.5–12.49 hours/day, n = 44; and >12.5, n = 65).

Language measures: As we described in the General Methods, a number of different language measures were obtained during the course of this study (Tomblin et al., this issue, pp. XXX). The selection of these measures for each wave of testing was dictated by our desire to have measures that were developmentally appropriate and that provided a broad coverage of dimensions of language in general as well as measures that would allow us to test particular hypotheses regarding features of language such as grammatical morphology or pragmatics. We also wanted our protocol to contain both measures derived from norm referenced standardized testing methods as well as those that reflected spontaneous, contextualized behaviors. Beyond these principles concerned with content and method, our selection of measures was constrained by the time that could be budgeted for language assessment at each assessment wave. The resulting set of language measures obtained across time was a by-product of several converging factors. Table 1 lists these standardized measures and shows the ages at which they were administered. All of these measures were administered and scored according the test manual using trained research assistants. Verification of test protocol conformity in terms of administration and scoring across sites was managed by an experienced research assistant. This subset of standardized measures was used for the analysis of patterns of language growth from 2 through 6 years. In addition to the standardized tests, this report also draws upon non-standardized measures of language. A 15-minute spontaneous language sample was obtained at age 3 and elicited measures of morphosyntax were obtained at age 4. We will describe the methods used for these measures in the relevant sections dealing with these measures.

Methodological preliminaries for analysis of language growth: Measuring language over development, particularly during the preschool years, is challenging as the skills that comprise language change considerably and thus different instruments must be used across development. In order to measure growth, these different measures need to be placed on a scale that reflects language ability. Two issues arise with regard to this point. First, the measures at each time and across time need to be measuring the same psychological trait. Thus, at any time point, we need evidence that the behaviors being measured are reflective of a coherent behavioral domain or trait and not several different traits. Furthermore, across time these measures need to be reflective of the same trait.

The second challenge is that these different measures of a single trait need to be placed on a common metric; that is, across measures we do not move from inches to centimeters to cubits. Ideally for growth analysis, this metric systematically increases across development. This type of scale can be developed using item response theory. In this study, we did not have measures that yielded item response theory scales. Many of our measures did provide scores of relative standing where children's ability levels were represented as a place in the normative distribution for the test. In this case then, a child whose absolute language ability across development retains the same position in the distribution will show no change in the language score. Children whose absolute growth falls behind or exceeds the growth of their age peers will have scores of relative standing that decrease or increase. These two issues – assuring that we are measuring the same thing over time with the various language measures and that the same scale was employed across time – will be addressed below.

Dimensionality of measures at each testing wave: We can see from Table 1 that language was measured at each wave of assessment using more than one test and that, in most cases, the tests contained subtests. This raised the issue of whether these different measures at each wave were measuring distinctly different language traits within a wave and across waves. To address this, we first used principal components analysis of these measures at each wave of data collection to determine the number of dimensions of language tapped by these measures.

The examination of the measurement properties of the language batteries was performed using both the CNH and CHH together. The Princomp procedure within SAS (9.3) was used to compute eigenvalues for each principal component for each measure at each test wave. This analysis revealed that at each wave, only the first principal component exceeded 1 and all the lower level principal components were well below 1. This analysis suggests that the measures of language at each age interval were all measuring the same ability trait. These results are quite consistent with several other studies of preschool and school-age children. There have been several studies involving normal hearing preschool children (Colledge et al. 2002; Anthony et al. 2014), kindergarten children (Tomblin et al. 2004), and elementary aged children (Law et al. 2008; Tomblin & Nippold 2014). In all these studies, we find similar evidence that despite different measures of language and different age groups, the core aspects of language consisting of vocabulary, syntax, and grammar, as well as narration, all seem to cohere into one principal component. These findings also are consistent with the conclusions of Bates and Goodman (2001) that these core aspects of language are inseparable.

This analysis also showed that the different measures loaded onto the first principal component to a similar degree. Thus, these findings supported the reduction of the language measures to a single language score for each child at each age level. These scores were computed by determining the mean norm referenced scale score for each child at each wave of testing where the scaled scores were all converted to have a mean of 100 and standard deviation of 15. In this way all the language scores reflected the children's relative standing in the combined normative groups for the child's age. These normative groups comprised CNH and thus provided a second normal hearing reference group along with our CNH group.

Correlations of language scores across age: The analysis above demonstrated that our standardized language measures could be combined at each age to form a single measure of language. We also needed to establish that these measures are reflective of the same construct across the age range. Because most of the children were seen for at least 3 years, we could examine the correlations between language scores over a period of 1 or 2 years. These correlations are shown in Table 2 and in all cases but one, the correlations were above 0.70. The correlation between language at 3 years of age and 5 years of age was 0.60; however, this cell also had the smallest sample size of those shown. These data support the notion that the language composite scores across age were measuring a very similar trait that was developmentally similar, even though the tasks and content changed over development.

Scaling comparability: Because we were using the normative samples for each measure as the reference groups, we needed to ask whether these normative samples were themselves comparable. If these norms were similar we should see stable scores for our sample across these different measures. Table 3 shows the summary descriptive statistics for these composite scores for each of the groups. Across ages there was some variability in the means; however, the profile of variability was quite similar for both groups. For both groups, similar scores were obtained at ages 2 and 4 years but at age 3 the scores declined. At ages 5 and 6, the scores for both groups increased relative to age 4. Thus, overall, there was a pattern of initial decline from age 2 to 3 and then an increase in scores at ages 5 and 6.

RESULTS

Language Outcomes of Children Who are Hard of Hearing Compared to Children with Normal Hearing—The data in Table 3 allow us to compare the overall language ability of the CHH with the CNH. We can see from Table 3 that the CHH were significantly lower than the CNH in language ability across the waves of testing. The difference between the groups as represented by the Cohen's *d* shows that the CHH were nearly 1 SD below the CNH by age 6. The size of the effect of mild to severe HL can also be seen by comparing the standard scores of the CHH with the test norms where we would expect an average score of 100. In this case, the data in Table 3 show that the average scores for the CHH fell below this expected score; however, the difference was often less than one-half a SD (7.5 points). We can also see in Table 3 that the CNH were systematically above the expected average score of 100 by between 6 and 12 points (1/3–2/3s of a SD). These data from the group of CNH suggest that our sample was likely to have been from homes that favored somewhat better language development. This is likely due to elevated parental education and household incomes. Such a bias wherein families from higher socioeconomic status homes are more likely to participate in research samples, particularly those that are longitudinal, is common. Because our CHH were similar to the CNH with regard to socioeconomic factors (see Methods section, it is likely that the CHH were also a biased sample (see Methods section, Tomblin et al., this issue, pp. XXX). That is, their language scores are likely to be better than the population of CHH in general. In light of this, the measure of the strength of the effect of HL on language seems best reflected by the contrast of the CHH with the CNH rather than the standardized test norms.

Influence of hearing levels on language development over time: A principal question addressed in this study concerned whether variations in hearing level as reflected in BEPTA were associated with overall differences in language development and/or differences in the rate of language growth. The data in Table 3 show that at each age level there were differences between groups in language ability, but in that analysis all levels of HL were treated as equal. We now ask whether levels of language development vary continuously across degree of HL and whether the differences in BEPTA are associated with differences in language growth trajectories. Thus, we examined the longitudinal data from the full cohort using mixed modeling via the Proc Mixed procedure within SAS. This analysis method allows us to account for repeated observations of the same children and tests parameters in a linear model that reflects children's initial level of language ability (intercept) and the rate of change in language ability over time (slope). These parameters served as random effects in the mixed model and then were tested for their degree of association with fixed effects that pertained to characteristics of the child. In all these mixed models, the predictor variables, with the exception of chronological age, were centered around the mean value. Age was centered at 2 years and thus the intercept values represent the language score for the children at age 2. Because we are interested in isolating the effects of HL on language growth, our analysis included maternal education as a covariate. Only those children who had at least two waves of data were included resulting in a loss of 45 CHH and 17 CNH, leaving 181 CHH and 79 CNH in this analysis. Recall that an inspection of the mean language scores across ages shown in Table 3 suggested that there might be a nonlinear trend to these data. Initially a model with just a linear term for age was compared with one that contained both a linear and quadratic age term. When these models were compared, the model with only the linear term was found to be a better fit to the data than the model that included a quadratic term. Thus, a quadratic term was not necessary for our multilevel modeling. We did find that the language scores trended higher across age, $F(1,302) = 13.31$, $p < 0.0003$, at the rate of 1 standard score point per year. This pattern of increasing levels of language for both CNH and CHH children can be seen in Table 3. Although we were using standard scores that were expected to have means of 100 across the age range, there was some drift that is particularly apparent at the ages of 5 and 6. This drift is likely due to differences in the normative populations used across the different test batteries.

Using the mixed modeling methods we examined whether average BEPTA was associated with differences in overall language levels and whether there were differences in language over time as a function of BEPTA. Table 4 shows the results of this analysis. These data are consistent with the previous findings summarized in Figure 3 in that we found a significant effect of hearing level across time such that increases in BEPTA across children (both CNH and CHH) were associated with decreases in language scores. This is reflected in the significant negative parameter of BEPTA in Table 3. The results also showed that there was no effect of BEPTA on language change across time (Age*Average BEPTA). That is, the slope value of 0.002 was not significant. Thus, we do not see any evidence of a divergence or convergence of the language scores over time. We did find that across age the scores increased 1 point per year and that this was significant. Likewise, maternal education was associated with differences in language (maternal education was treated categorically and thus parameter values were not provided). Figure 2 summarizes these growth trajectories for the four categories of HL. These data show the trend in language scores for all groups to increase and that the language scores systematically decline as the HL increases; however, the patterns of language level across age are parallel across the groups and thus do not show a differential pattern of change in relation to HL.

As a supplementary analysis to this growth analysis, the language scores shown in Figure 2 were averaged over chronological age and a one-way analysis of variance (ANOVA) was performed to test for overall differences in language among the groups. As expected, the language ability was significantly different, $F(3,386) = 27.24$, $p < .0001$, $\eta^2 = 0.18$, across the groups. Post hoc Tukey tests showed that the CNH were significantly better than all groups of CHH. The CHH with mild losses were significantly better than CHH with moderate-severe losses. There were no significant differences between mild and moderate groups.

Effects of Audibility of HAs on Language Development in CHH: In the analysis above, the children's hearing ability was indexed by their unaided BEPTA. As we noted earlier, the CHH can be thought of having two levels of hearing; one, their unaided hearing and the other, their aided hearing. We hypothesized that aided hearing should influence the child's language beyond that of the child's overall hearing severity. Our measure of HA benefit given the child's unaided hearing (rSII) was therefore examined with regard to its association with language status during the 2- to 6-year-old period. In this case, because we were asking about aided hearing, the sample was now limited to the CHH who were HA users.

In this analysis, we see that rSII did not have an overall effect on language ability (Average rSII parameter 2.60, $p = 0.88$); however, rSII was significantly associated with differential growth (Age*rSII slope 16.09, $p = 0.009$). This effect can be seen in Figure 3. The CHH were grouped into four quartile groups based on their rSII. These data show that at age 2 the groups had similar language abilities; subsequently, there were very different trajectories of language growth. The overall pattern is one of an expanding fan with children who were receiving the most benefit from their HA demonstrating a positive pattern of growth. That is, they were improving their language against levels of language relative to the test norms. In contrast the children who received the smallest HA benefit (lowest rSII) show no evidence of any change in language level. By 6 years of age this cumulative effect resulted in the children in the top quartile having language abilities 10 standard score points greater than the children in the bottom quartile. This difference represented two-thirds of a standard deviation, thus the cumulative effect of degree of relative HA benefit over 4 years was large. It is important to note that this differential effect of HA benefit across time was independent of the severity of unaided hearing. Within this group of children, rSII was not significantly correlated with BEPTA $r(163)=-0.13$, $p=0.09$) and the BEPTA of the children in the lowest quartile of rSII in Figure 3 had an average BEPTA of 53.16 ($SD=15.61$) while the children with the highest quartile of rSII had a BEPTA of 49.61 ($SD=8.01$) and this difference was not significant $t(84.45)=1.46$, $p=0.18$. Thus, the evidence of HA benefit for language development holds for CHH with mild to severe levels of unaided hearing.

Effect of age at Hearing Aid fit and Duration of Hearing Aid use on Language Development: Current practice dictates that early HA fitting is critical. It has been shown that receipt of an auditory prosthesis such as a HA or cochlear implant early in life provides benefits for language development over later fitting of an auditory prosthesis (Yoshinaga-Itano et al. 1998; Tomblin et al. 2005). At least three related factors could account for these effects. Early fitting increases the length of time during development that the child can receive benefit – that is, it increases the dose of the treatment. Likewise, early fitting also reduces the length of time that the HL is untreated. Finally, early fitting might provide important auditory experience at a time during brain development when the brain is especially sensitive to this experience. Thus, we asked whether there was an association between age of HA fitting and language outcome among the children with HL. We also asked whether this benefit was associated with the length of use after accounting for age of fit or whether these two related variables interacted. We again tested for the effects of age at HA fit and duration of HA use within a mixed model where chronological age was treated as a random effect over which growth could occur and HA fit was a fixed effect. The relationship between age at HA fit and the child's chronological age at the time of testing equals the child's duration of HA use. Thus, although our model examined language growth over chronological age, this variable in fact represented duration of HA use. Very few children entered this study without HAs, thus most of the language data were obtained after some period of HA use. Only two CHH were fit with HAs after their initial enrollment in the study. In these cases, we restricted our analysis to the language scores each child obtained subsequent to HA fitting. The 7 CHH who did not wear HAs were not included in this analysis. Figure 4 shows the distribution of age of HA fit for the children in this analysis.

The results of the mixed modeling analysis are shown in Table 5. This analysis showed that there were significant main effects of 1) chronological age, which in this model reflects amount of HA use at that age point, and 2) age at HA fitting. These two main effects interacted significantly. The nature of this interaction can be seen in Figure 5 where the predicted growth in language scores across time is plotted for children who were fitted within time periods. There are three 6-month intervals plus a fourth open-ended period for children who received their HAs after 18 months of age. In order to interpret the data in Figure 4, it is helpful to examine the data in Table 7, where the average duration of HA use is provided for each of the age at HA fit groups at each chronological age interval. These data show that duration of HA use increases with increases in chronological age. This plot shows that the interaction between age of HA fit and advancing chronological age and duration of HA use involves a decline in the size of the age of fit effect across time. At age 2, the differences between age of fit groups was relatively large and significant when tested via ANOVA at this age, $F(3, 95) = 6.08$, $p = 0.0008$, but by 6 years of age the group differences across age at fit declined and were no longer significant, $F(3, 103) = 2.49$, $p = 0.065$.

These data clearly show that the children who received HAs before 6 months of age showed less change during the 2 to 6 year old age range, however, their level of stable language achievement was within the average range throughout the 2 to 6 year age range. Thus, it is likely that benefits of HA use for these children receiving HAs earlier either protected them from falling behind or provided for early catch up prior to the age of 2 years. The data show that the children who received HAs later had lower language abilities at the 2 year age interval than the children fit early; however this effect of early HA fitting declined. Thus, the children with later HA fitting showed a pattern of "catching up" which supports the benefits of wearing HAs over time during the preschool years. Particularly for those children who received their HAs after 6 months, it is also quite possible that other factors such as progressive loss and/or receipt of educational interventions also contributed to these gains. We were able to test whether these findings might be due to later onset HL that would then be confounded with later HA fitting by running this analysis on only those children who had passed their newborn hearing screening thus excluding children with delayed-onset or progressive HL. This analysis yielded similar results. Importantly, the parameter for the interaction term of 0.12 was significant, $F(1, 85) = 9.71$, $p = 0.002$, and in fact was greater than in the analysis that included later identified children. Thus, these findings do hold for children who had HL at birth.

Overall, these data clearly point to a positive effect of HA use on language over time. They also show that early fitting does provide better language outcomes during much of the preschool years. Thus, early HA fitting is clearly supported. However, these data also show that later receipt of HAs does not seem to result in irreversible deficits in language. The benefits of early HA receipt are more likely due to the longer duration afforded by early fitting than to there being a critical period in infancy that once closed cannot be altered. These data could be consistent with a sensitive period of development wherein early experience is more effective for language learning than later input. (See Tomblin et al. 2007 for discussion of critical and sensitive periods.)

Effect of daily hearing aid use on language development: The measure of duration of HA use examined above reflects long-term HA use. However, a potentially important factor in the influence of HAs on language development concerns the amount of time during the day that the child wears the HAs. Within our framework of access to speech, we would expect that greater daily use of a HA would provide better access and thus also better language outcomes. Figure 6 shows the average language composite scores across the waves of observation in relation to their average daily HA use across observation waves as reported by the parents. It is also reasonable to assume that the importance of HA use for language development will differ depending on the severity of unaided hearing (BEPTA). Therefore, the data in Figure 6 contrasted the children according to the severity of their BEPTA.

The data shown in Figure 6 were tested via an ANOVA for the effects of daily HA use and its interaction with severity of HL. Because the home environment (as indexed by maternal education) is known to be associated with both HA use (see Walker et al. 2013) and language we included mother's education as a covariate. This analysis confirmed that average HA use was significantly associated with better language outcomes, $F(3, 243) = 3.13$, $p = 0.03$. Also, average BEPTA was significantly associated with language outcome, $F(2,243) = 9.67$, $p = 0.0001$. However, the interaction between HA use and severity of HL was not significant, $F(6, 243) = 1.43$, $p = 0.21$, indicating that HA use was associated with language outcomes independent of the severity of the HL. Inspection of the data in Figure 6 does not show evidence of an effect of daily HA use among the children with average BEPTAs less than 45 dB HL. In contrast, greater use does appear associated with better language outcomes in the children with average BEPTAs >44 dB HL. Thus, there is the possibility that an interaction between severity of loss and daily HA use does exist, but this study was not sufficiently powered to detect this interaction.

The analysis above was performed on the grand mean of the language standard scores averaged across time. We have seen that duration of HA use affects differential language growth rates. This leads us to use mixed modeling to determine whether differences in daily use also resulted in differences in language growth. In this case the model was similar to that used in the prior analyses where maternal education and severity of hearing (BEPTA) were included as covariates and then the effects of daily HA use were tested by examining its interaction with chronological age. The results of this analysis are shown in Table 8. The key results of this analysis confirmed that differences in daily HA use did lead to differential growth in language over time in HA users. The positive parameter value for the interaction between hours of HA use and age indicates that greater amount of daily HA use was associated with greater amount of change in language over time. The nature of this differential growth pattern is shown in Figure 7. In this case the children who were wearing their HAs for less than 10 hours a day showed no change in language whereas those wearing their HAs for more than 10 hours a day showed gains in language ability between 2 and 6 years of age. This finding provides evidence that the amount of daily HA use does have an influence on the development of language during the preschool years.

Study 2: Spontaneous Language Outcomes at 3 Years of Age

The growth analysis performed above was based on standardized measures of language obtained either by parent report or by direct testing. These measures allowed us to form norm-referenced scores at each age that provided suitable scaling for growth analysis. Although these measures are generally viewed as valid indicators of language ability, the information they provide about children's language skills may not be as rich or representative of language abilities in a natural conversational context as measures of various aspects of language derived from spontaneous language samples. In contrast with standardized language tests, conversational language allows the child to choose what to say, how to say it, and how much to say. Standardized tests typically specify the kind of language response and constrain the amount and variety of response, thus we might expect that standardized tests provide a different view of language than that shown in conversational language. Support for this was provided by Tomblin et al. (2014a) who used principal components analysis to examine the dimensionality of language measures in school age children. This analysis showed that standardized language tests loaded on one common factor that was distinct from three others related to the child's fluency of language expression, degree of utterance complexity, and talkativeness. DeThorne et al. (2008) also reported a similar distinction between language measured via standardized test versus spontaneous language. Thus, we need to ask whether our findings with regard to language growth in CHH using standardized measures may also apply to CHH's language skills reflected in conversation.

METHOD

To examine language skills reflected in conversation, our methods entailed obtaining a 15-minute conversational sample from the 3-year-old CHH (*n* = 91) and CNH (*n* = 39) while they were engaged in a conversation with their parent or examiner. These samples were audio-video recorded. The videos were transcribed using the transcription conventions of Systematic Analysis of Language Transcripts and analyzed using this software, which provides a number of indices of language (Miller & Chapman 1998). Additionally, these transcripts were scored for developmental sentence complexity based on the Developmental Sentence Scoring scheme (Lee 1974). The measures we obtained are shown in Table 7.

RESULTS

Dimensions of Variables Obtained—The measures in Table 9 were all drawn from a fixed language corpora and by their nature are not independent of each other. For instance, the number of utterances per minute will be related to the total number of utterances since the time was fixed at 15 minutes. A child who speaks more utterances per minute will have a higher total number of utterances. Thus, we used a principal components analysis to reduce the set of measures. We required that a factor have an eigenvalue of 1 or greater to be considered. We also examined the scree plot for evidence a distinct knee. Variables that loaded at greater than 35 were treated as indicators of that factor. As shown in Table 9, two principal components were obtained. Six measures loaded on the first factor. These were measures of utterance length, use of bound morphemes, number of mazed words, number of different words, and developmental sentence scores. These measures can be interpreted to be reflective of the child's command of language with respect to sentence structure and content or language quality. The second factor was formed by measures of total number of words and utterances, words per minute, and omitted words. These measures appear to reflect language quantity or the amount of talking the child engaged in. This principal components analysis provided us with a means of creating factor scores for each child that represent each of these aspects of conversational performance.

Relationship of Spontaneous Measures to Standardized Test Measures—Recall from Table 1 that at the 3-year wave of assessment we obtained standardized measures of language using the Comprehensive Assessment of Spoken Language Core and the receptive and expressive language measures from the Vineland. These were used as the 3-year-old measures for the growth analysis. We can now ask whether these standardized measures of language are reflective of the child's use of language in a natural conversational setting. Each of these standardized measures was correlated with the two factor scores representing language quality and language quantity. Table 10 shows that these standardized measures were strongly correlated with the children's quality of language within the conversations, but were not associated with the quantity of their conversational participation. Conversational language samples were also obtained at the 6-year wave. These analyses have been performed on only 66 children. Despite this limited sample, we obtained the same factor structure that reflected quality of language (structure and content) and quantity dimensions. Again the composite standardized language scores used in the growth analysis were strongly correlated with the quality factor, r (66) = 0.72, $p < .0001$, and were not correlated with the quantity factor, $r(66) = -0.10$, $p = 0.44$. These findings provide validating evidence that the results regarding language growth using the standardized measures across the ages of 2 through 6 are likely to be representative of the children's language abilities in more naturalistic conditions.

Relationships of hearing status and spontaneous language at 3 years—Given that the spontaneous language measures were reflective of two different dimensions of communication, we asked whether the children's hearing status was associated with either of these dimensions of communication. For this analysis, unaided hearing was represented by the same four levels of BEPTA hearing thresholds used in previous analyses (see Figure 2). An analysis of covariance (ANCOVA) in which household income was included as a covariate showed that there was a significant effect of pure tone hearing level on Factor 1 (Quality of Language), $F(3, 110) = 7.52$, $p = 0.0002$, partial η^2 of 0.16, but there was not a significant association of Factor 2 (Quantity of Language) with hearing level, $F(3,110) = 0.39$, $p = 0.76$, partial η^2 0.01. Figure 8 shows the distribution of mean scores for Factor 1 by hearing level. A post hoc analysis for Factor 1 showed that children with hearing levels greater than 45 dB HL were significantly poorer than the CNH (hearing levels < 20 dB HL) and also, children with mild losses (25–45 dB HL) had significantly better language than the children with hearing levels greater than 60 dB HL. The values shown for Factor 1 in Figure 8 are in *z*-score units where the standard deviation is 1. The difference between the CNH and the children with moderate HL (45–60 dB HL) was .71 and for the children with moderate-to-severe HL (> 60 dB HL) was .95. These differences were significant $p < .05$ and can be viewed as Cohen's *d*s and thus are in the medium to large size.

Study 3: Differential Effects of HL on Morphosyntax and Vocabulary

We have hypothesized that some aspects of language are more dependent upon access to phonetic details of the speech signal than others. Leonard and colleagues (Leonard 1989; Leonard et al. 1997; Svirsky et al. 2002) have proposed that inflectional morphemes of English are not perceptually prominent and thus acquisition of these forms can be challenging particularly in children with HL. We have demonstrated some evidence for this by examining syntactic and morphological use in spontaneous language samples produced by the children in this cohort at 3 and 6 years of age (Koehlinger et al. 2013). In this case, the CHH were found to produce less complex sentences and fewer obligatory morphological terms. Recently, Huysmans and colleagues (2014), demonstrated that adults with congenital mild to severe HL made a significantly greater number of morphological errors in Dutch than subjects with normal hearing, and the two groups did not differ with regard to syntactic properties of their spontaneous language. These studies and others (Blamey et al. 2001; McGuckian & Henry 2007) support the prediction that we should find a stronger relationship between levels of hearing (represented by BEPTA) and morphology than levels of hearing and lexical development, where phonetic cues are more prominent and redundant.

METHODS

As described in the General Methods at the ages of 3 and 4 a morphological elicitation task was administered (Tomblin et al., this issue, pp. XXX). This measure was designed to examine whether morphosyntax was particularly sensitive to the effects of reduced auditory access. We found that this task was quite challenging for many children at 3 years of age, resulting in a floor effect. Thus, in this report we will limit the analysis to the 223 (CNH = 69, CHH = 154) 4-year-old children.

At 4 years of age, the children were given a set of standardized language tests as shown in the Appendix of the General Methods (Tomblin et al., this issue). These tests were the Wechsler Preschool and Primary Scale of Intelligence Vocabulary subtest and three subtests of the Comprehensive Assessment of Spoken Language: Syntax, Basic Concepts, and Pragmatics. The Vocabulary and Basic Concepts subtests of these measures served as measures of lexical development. Morphology was measured using an experimental task involving probes for a set of bound morphemes. This task tapped regular and irregular plural, possessives, third person number agreement, regular and irregular past copula be, auxiliary be, and progressive.

The different items in this task varied with regard to difficulty and as a result there were several children who were unable to provide a response to some items. The rate of these nonresponses is shown in Table 11. The children who did not respond were children with the lowest language ability. By treating these responses as missing, a systematic bias is introduced where data are only presented for the more able children. If we assigned a score of 0, we would be indicating that this was our best estimate of the child’s ability. The alternative was to use the child’s responses to the other items to impute the missing data. Such imputation allows for an “informed guess” of the child’s ability and also provides for an index of confidence around this “guess” that can be incorporated into subsequent analyses. Thus, instances of missing data due to no response were imputed using the multiple imputation procedure of SAS. The data matrix for the imputation consisted of scores obtained on the elicited morphological task and the child’s score on the Syntax test of the Comprehensive Assessment of Spoken Language. Table 11 shows that this imputation resulted in very high levels of efficiency. The multiple imputation generated five score imputations. For each of these imputation runs, the average morphology score for the third person, regular past, possessive, and aux was computed and transformed to *z*-scores. This set of five average morphological scores, each representing a single imputation, were then submitted to a general linear model via the SAS Minanalyze procedure that incorporates the uncertainty information from the multiple imputation.

RESULTS

We had hypothesized that morphology would be more strongly associated with children’s hearing abilities than vocabulary due to the low phonetic prominence of bound morphemes in English. A multiple regression was performed within the General Linear Model procedure of SAS testing the relationship between BEPTA and the morphology and lexical scores across the CNH and CHH. In this analysis, the scores of the CHH were normalized on the CNH. This analysis was performed separately for each of the five imputed data sets. The parameters obtained from these five sets were then tested within the minanalyze procedure. The summary data for this analysis are shown in Figure 9 where the error bars represent the standard error for the means derived from the multiple imputation. From this analysis we found that the regression parameter for the relationship between morphology and BEPTA, after entering lexical scores, was −5.30 which was significant, $t(1) = -3.31$, $p < 0.0009$, whereas the parameter for the lexical measure after accounting for morphology was −1.98, which was not significant $t(1) = -1.16$ p>.05. A similar analysis was performed, but in this case we examined the relationship between rSII and morphology and vocabulary. Again, morphology was significantly associated with rSII, slope = 0.02, $t(1) = 1.99$, $p = .05$, where the lexical measure was not significantly associated with rSII after controlling for morphology, slope = 0.006, $t(1) = 0.5$, $p = 0.61$. Thus, we can see that morphology appears to have a specific relationship with hearing beyond that found for word learning. This relationship is consistent with the notion that morphology may be an aspect of language that is more vulnerable in children with HL than other aspects of language. Furthermore, these data suggest that the improved audibility provided by HAs can protect against this vulnerability.

GENERAL DISCUSSION

Hearing level and language ability

We began this study with a general theory that successful language development required early and consistent access to the diverse set of auditory cues that comprise language. We hypothesized that mild to severe HL in early childhood threatened this access. Furthermore, we hypothesized that early, well-fit HAs that were worn regularly could moderate this threat. The existing literature has been mixed with regard to whether language outcomes in CHH are threatened and there has been very little research concerning whether the fitting and use of HAs provides any protection. The data obtained in this study largely support the predictions made and thus the data suggest CHH do show depressed levels of language development during the preschool years in comparison with their age mates with normal hearing. Furthermore, the degree to which these CHH fall behind the CNH increases with the severity of the unaided level of HL. Children with more severe HL, on average, had poorer language outcomes during the preschool years than children with milder losses. This effect of severity of HL on language held across preschool development and did not show signs of cumulative effects that would result in an increase in language variation among CHH over time.

The finding of a relationship between degree of HL and language outcomes is in concert with the conclusions of recent population-based studies (Wake et al. 2005; Ching et al. 2013). However, the current study offers unique insights by exploring the contribution of unaided hearing to longitudinal growth curves in a well-defined group of CHH. Language levels increased with age across all HL levels, but the patterns of growth were essentially parallel, showing a stable effect of degree of HL. We contend that these results support the hypothesis that restrictions in language access over time impact language learning; logically we infer that access to linguistic input reduces as a function of increased severity of HL.

The current study was designed to explore multiple factors that may moderate the impact of degree of HL on language learning outcomes, which is critical for gaining insights into individual differences. A limitation of previous studies of CHH was the failure to consider the influence of consistency and duration of aided hearing, which arguably is critical for language learning in this group. In fact, one previous study concluded that poorly performing children with mild and moderate HL (half of their participants) consisted of language-impaired children who happened to have HL (Gilbertson & Kamhi 1995). In this study the severity of the HL itself was not associated with language outcomes. Thus, these authors reasoned that hearing status was not a cause of the poor language development in the subgroup of CHH with poor language. Gilbertson and Kamhi argued that language impairment unrelated to HL was common among CHH; however, it is very unlikely that the prevalence of such language impairment is as high as 50%. Indeed, the results of this current study showed that CHH can vary with regard to their language outcomes due to a number of auditory access factors beyond their unaided hearing and therefore it may be premature to assume that CHH who have poor language do so for the same reason that CNH with normal hearing (e.g. children with SLI) have poor language.

Mild to severe hearing loss and disability

The findings from this study provide consistent evidence that limitations in hearing sensitivity have an impact on children's development of language. It can be argued, however, that this effect is not sufficient to lead to a disabling condition in most of these children. In this sample, when the CHH were compared to the CNH who contributed to the normative samples of the standardized tests, we find that the CHH as a whole were about a third of a standard deviation (5 standard score points) below the normative sample. This difference could be interpreted as suggesting that mild to severe HL is benign. Before reaching this conclusion we need to consider some additional issues.

Generally, language that is viewed as clinically concerning falls at −1.25 or poorer (Tomblin et al. 1996). Thus, we might conclude that mild to severe HL is not a risk condition at least with regard to spoken language development. We believe such a conclusion overlooks some important factors. First, it is important to emphasize that most of the children in this study were wearing HAs. This study is the first to examine the effects of HAs on language outcomes on a large cohort of children with mild to severe HL. As will be discussed below, our data show that HA use moderates the effects of HL on language development. Thus, we cannot use these data to argue that mild to severe HL when untreated with HAs does not pose of threat. Secondly, research studies, particularly longitudinal studies such as this one, are well known to enroll a biased sample of participants. It is much more difficult for families with limited means to take the time to participate and families from less advantaged backgrounds are more likely to move away from the research site and be lost to follow-up. When we compared the CHH to CNH who were largely matched on socioeconomic status, the magnitude of the effect of HL on language doubled to two-thirds of a standard deviation. Such a shift in the distribution has the effect of increasing the number of children who would fall below the 10^{th} percentile by 2.6 times. That is, while we might expect 100 children out of 1,000 to be below the 10^{th} percentile, we would now have 264 children or more than 25% who meet that expectation.

These results also lead us to question the sole reliance on comparison to standardized test norms for judging the adequacy of the developmental outcomes of CHH. It could be argued that CHH will compete in school settings with children from similar familial backgrounds. In the current study, comparison of the CHH to the socioeconomic status matched sample of

CNH leads to different conclusions about the level of developmental risks beyond simple comparison to test normative samples. Rescorla (2000) also raised this issue in her study of reading outcomes of late-takers. She noted that these children had substantially poorer reading performance than their peers matched on socioeconomic status even though these reading levels were not in the range considered for reading disorder and she therefore argued that local norm comparison was more appropriate.. Blair, Peterson, and Viehweg (1985) raised a similar concern. They found that conclusions made about the academic progress of children with mild HL differed based on comparison to peers from the same school district or to national normative data. Children with mild HL were significantly delayed compared to grade-mates but not national norms. Our future research efforts will explore the degree to which early language delays or early language performance in the lower end of the average range may have cascading effects on later academic performance.

Hearing aids and risk modification

Several aspects of the data demonstrated that the fitting and use of HAs provides improved language outcomes. First, we found that the degree to which the HA fit provided improved audibility relative to unaided hearing was associated with differential rate of language change over time. Specifically, there was an increase in language variation over time as a function of audibility, resulting in a fan effect. Children who received above-average audibility showed gains in language development relative to CNH whereas children with below average audibility showed declines in language development relative to CNH. Because these measures of audibility were relative to the child's unaided hearing, the benefits found for improved audibility hold for CHH across the severity spectrum that included children with mild HL. Stiles et al. (2012) reported the positive influence of high levels of aided audibility on language outcomes in school-age CHH. The current study extends those findings by demonstrating the contributions of aided audibility to language growth in a large group of preschoolers. This finding supports the practice of HA verification and related efforts to optimize audibility with amplification. This is a malleable factor in service delivery for young CHH, yet previous evidence suggests that there is a need for improvement in these practices (McCreery et al. 2013). The current study provides empirical support for vigilance in optimizing audibility.

The incorporation of a new measure, the residualized SII, results in a purer measure of the boost provided by HAs, allowing us to isolate the contributions of HAs on language outcomes and avoid the confounding association between BEPTA and SII values (Tomblin et al. 2014b). We agree with Stiles and colleagues (2012) that aided audibility measures may provide better estimates of the child's functional hearing than pure tone averages. Further research is needed, however, given that both BEPTA and SII are known to have limitations for predicting speech intelligibility scores in children (McCreery & Stelmachowicz, 2011).

Further evidence of the benefit of HAs was found in the analysis of the age at HA fitting and duration of HA use. Early HA fitting was associated with better early language achievement in comparison with children fit later. All but 98 CHH in this cohort had received their HAs by 18 months of age and 50% of them had received HAs before 7 months of age. The children fit before 6 months showed, on average, good levels of language development by the age of 2 years. In contrast, the children who received their HAs after 18 months of age showed much lower levels of early language development. Similar findings were reported by our research team for early speech production (Ambrose et al. 2014). In CHH, better speech production outcomes at 2 years of age were associated with HA fitting before 6 months of age. Although a recent prospective study concluded that age at HA fitting did not influence children's language outcomes at age three years (Ching et al. 2013), our current results are consistent with the findings of Sininger et al. (2010) documenting such an effect. The current study identified an interaction between duration of HA use and age of HA fit. Children fit early appear to have an early advantage in language development. Children fit prior to 6 months had the longest duration of HA use and demonstrated the strongest average scores across the age span compared to later-fit children. Children fit later narrowed the gap with earlier-fit peers by 6 years of age. In this respect, it could be argued that later fitting has only temporary effects on language development and may not have lifelong consequences. We would caution, however, that despite this closing of the gap in later preschool, these early delays evidenced by later-fit children could have negative effects on the child during the early years. Thus, even though this delay in language development may largely resolve, it may not be entirely benign.

The interaction findings also support the conclusion that HAs offer benefits for both CHH fit early and those fit later in the preschool years. Importantly, the CHH who were fit early showed strong language performance across the age span from 2 to 6 years. Thus, the children who had better access to language during the first 2 years of life due to the fitting and use of HAs profited from this experience. The data also showed that over time even children who received HAs later in the preschool years improved in their language ability as a function of this HA use. As the amount of HA use increased, their language abilities relative to CNH in the normative samples also increased. These findings again provide evidence for the benefit of HA use on language development. Furthermore, they show that the language learning system remains open to experience provided by this improved audibility. The fact that children who were fitted later in infancy and toddlerhood showed these gains in language suggest that the brain remains plastic and open to experience-dependent changes through the preschool years. Thus, if there is a sensitive period for language development it appears to be rather broad and not limited to early infancy.

In addition to age at fitting and duration of HA use, our findings suggest that consistent wearing of devices contributes to language outcomes. The results indicated that daily HA use was significantly associated with language outcomes independent of severity of HL. The data also suggest that consistent HA use provides particular benefit for children with moderately-severe HL. Five of the children in this HL category were reported to have low device use. They had average language standard scores of 73, suggesting a clinically significant impact of reduced daily HA use. These data support clinical efforts to promote consistent HA use, which our previous results indicate is least consistent in toddlers and in children with mild HL (Walker et al. 2013).

Quantitative and qualitative dimensions of spontaneous language measures

Conversational language samples collected at 3 years of age were found to reflect quantitative (amount or volubility) and qualitative (form and content) dimensions. Interestingly, hearing variables were not predictive of quantity dimensions, but were related to quality dimensions. In the article on linguistic input (this issue, pp. xxxx), Ambrose and colleagues reported that quality, but not quantity, of caregiver linguistic input at 18 months was related to child language abilities at 3 years. This distinction between quality and quantity dimensions provides some insights about measures that may be more sensitive to assessing developmental needs in CHH. Qualitative measures derived from language samples may be more informative than measures of volubility. Furthermore, this analysis revealed strong concordance between quality measures from the language samples and standardized language measures, adding to the evidence regarding concurrent validity. As noted above, the conversational language measures provide information regarding information about the degree to which the child engaged in the conversation (quantity) that is not reflected in the standardized language measures. Thus, the data further support the value of conversational language measures as complements to standardized measures.

Differential effects of hearing loss on domains of language

The inconsistent access hypothesis predicted that domains of language development that are dependent on processing phonetic details in the input would be especially vulnerable to the effects of HL. As we noted earlier, this prediction is grounded on the surface hypothesis of Leonard (1989) which argues that the grammatical morphemes of English are perceptually subtle. Furthermore, in English, these morphemes are found within inconsistent paradigms (e.g. both regular and irregular morphological rules) that can make acquisition of these grammatical systems more challenging. We explored the prediction that grammatical morphology could be particularly challenging to CHH, by examining outcomes in morphosyntax in relation to lexical development. We reasoned that morphosyntax is especially dependent on access to phonetic details within the linguistic input, whereas lexical cues may occur with greater support and redundancy. In English, morphemes are often represented by phonemes that are challenging to hear [s, z, t], occur in sentential positions that lead to reduced amplitude, or vary in their frequency of occurrence in the input (Hsieh et al. 1999). Our results confirm that the CHH demonstrated poorer performance in morphology than lexical development at age 4 years. In addition, the analysis shows a specific relationship with morphology and hearing abilities, which suggests that morphology may be an aspect of language that is especially vulnerable in CHH. Because better audibility was associated with better performance in morphology, there is further strong support for optimizing amplification to protect against this risk. Furthermore, there is justification for closely monitoring and supporting morphosyntactic development in CHH.

Summary

The data obtained in this study suggest that mild to severe HL places children at risk for delays in language development, especially when HL is moderate or greater. Risks are moderated by the provision of early access to well-fit HAs that provide optimized audibility, especially when HAs are worn consistently. Risk was especially high in morphosyntax, an area with high demands on processing of fine details in the linguistic input.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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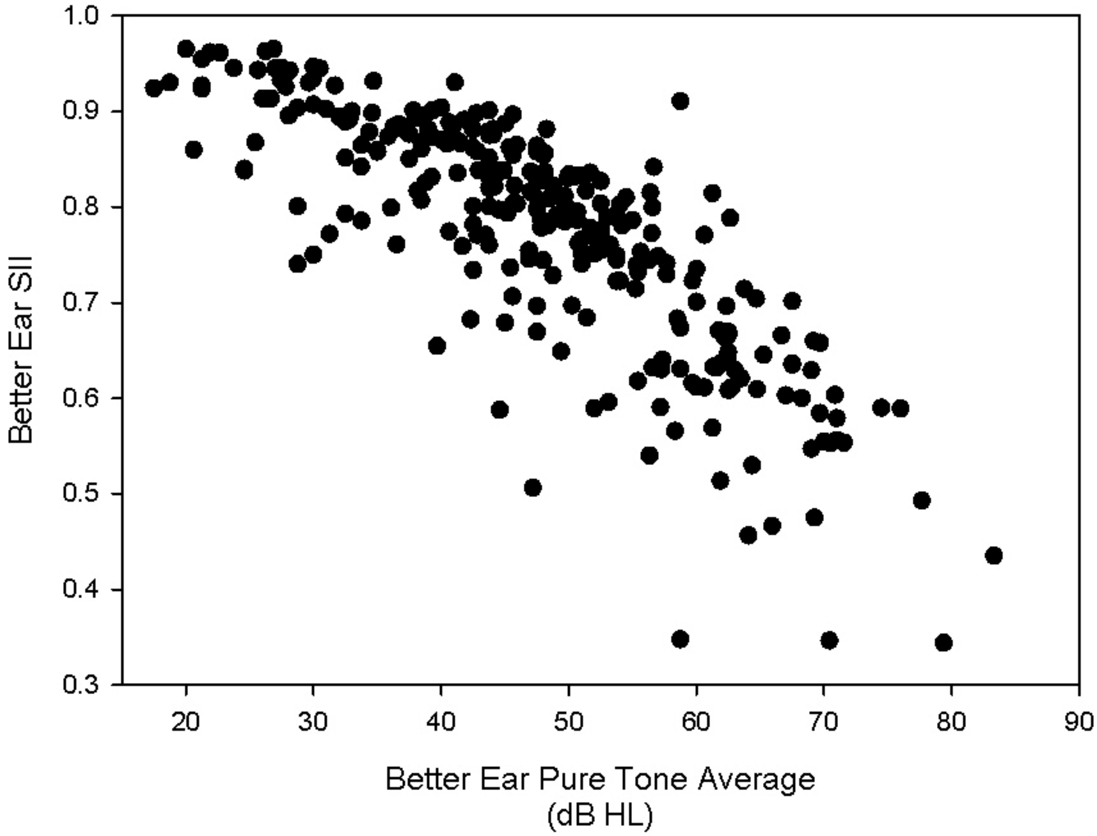

Figure 1.

Relationship between better ear pure tone average and better ear aided speech intelligibility index (SII)

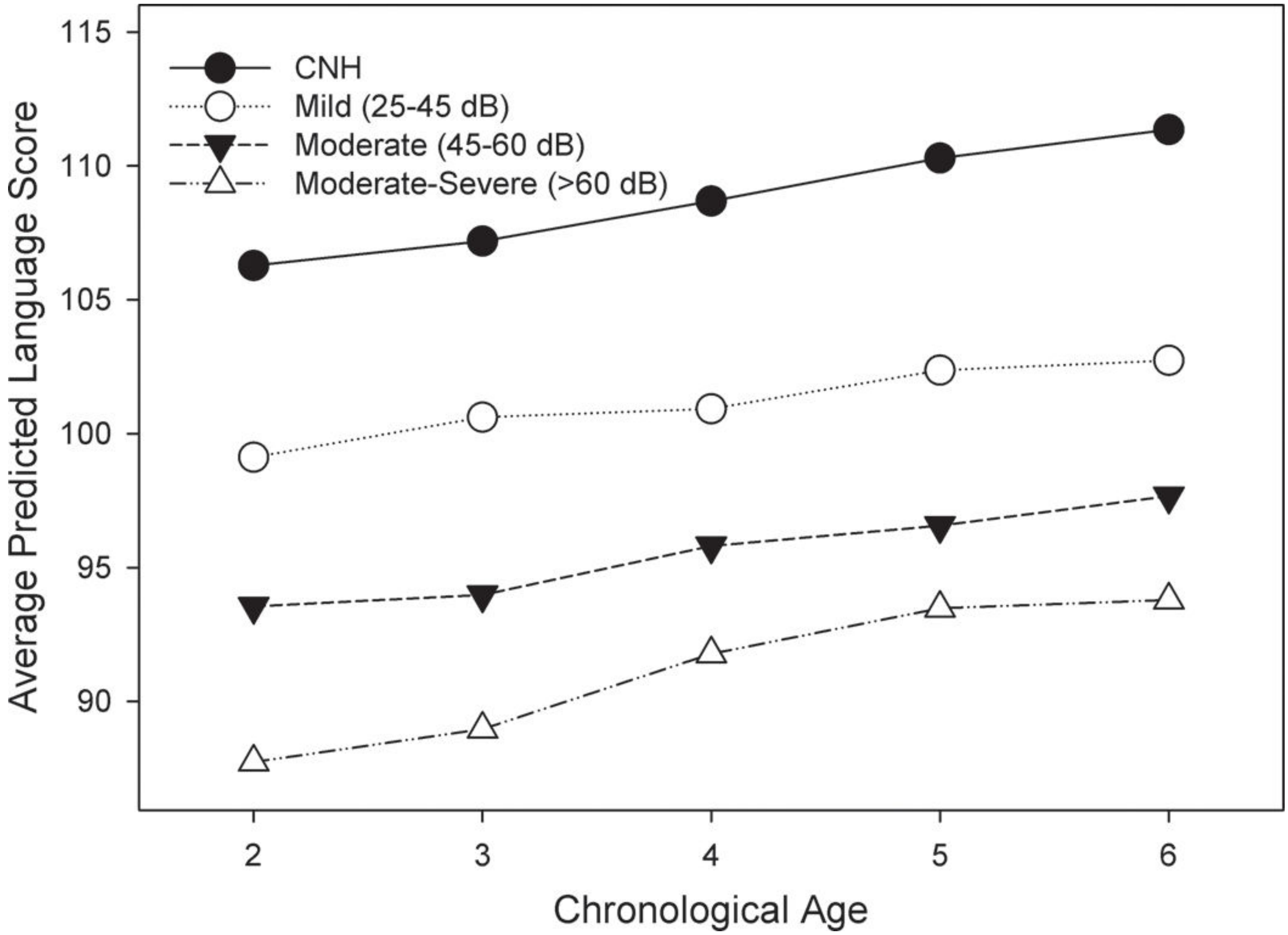

Figure 2.
Average predicted language scores based on mixed model across ages 2 through 6 years for children with normal hearing (CNH) and children who are hard of hearing grouped by severity of unaided hearing loss.

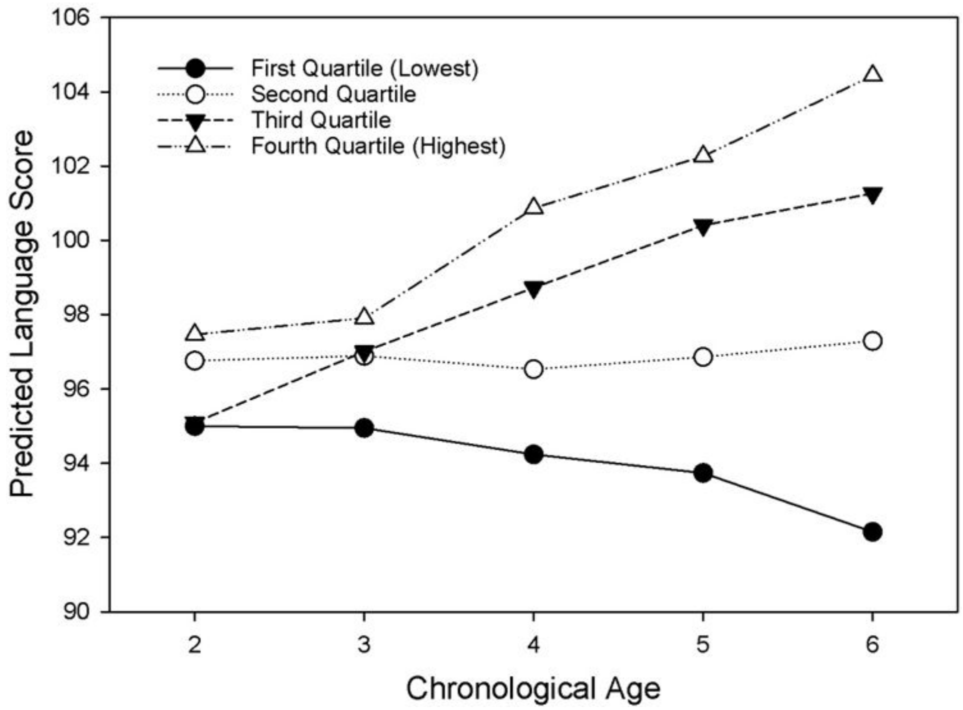

Figure 3.

Averages of predicted language scores based on mixed model for children who are hard of hearing across ages 2 through 6 years with different levels of residualized SII (rSII).

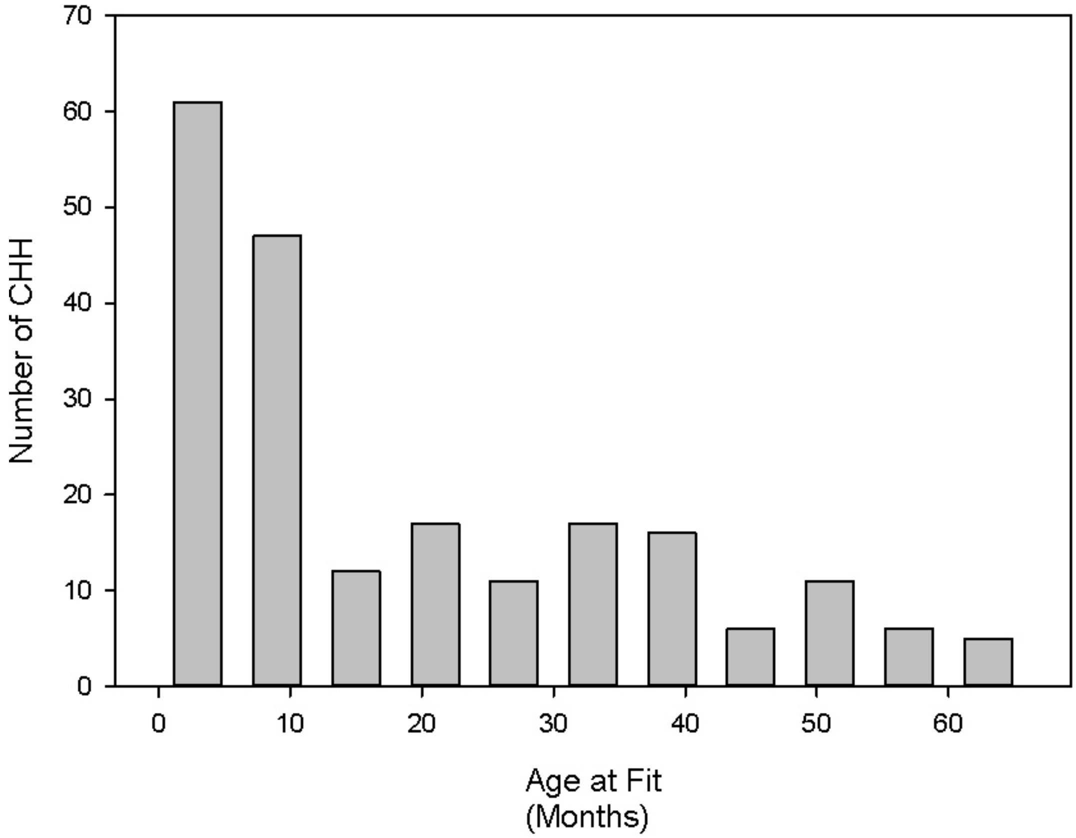

Figure 4.
Distribution of the age of hearing aid fit in the sample of children who are hard of hearing (CHH).

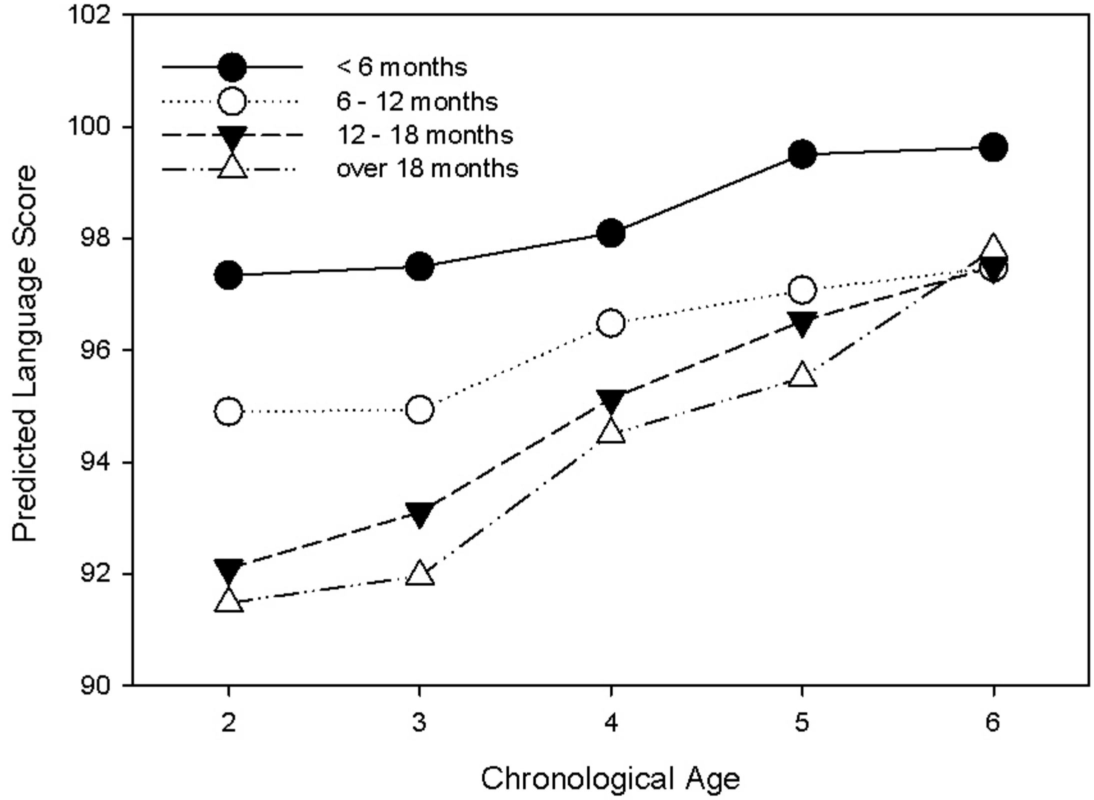

Figure 5.

Averages of predicted language scores based on mixed model across the ages of 2 through 6 years for children receiving hearing aids at 0–6, 6–12, 12–18, and over 18 months.

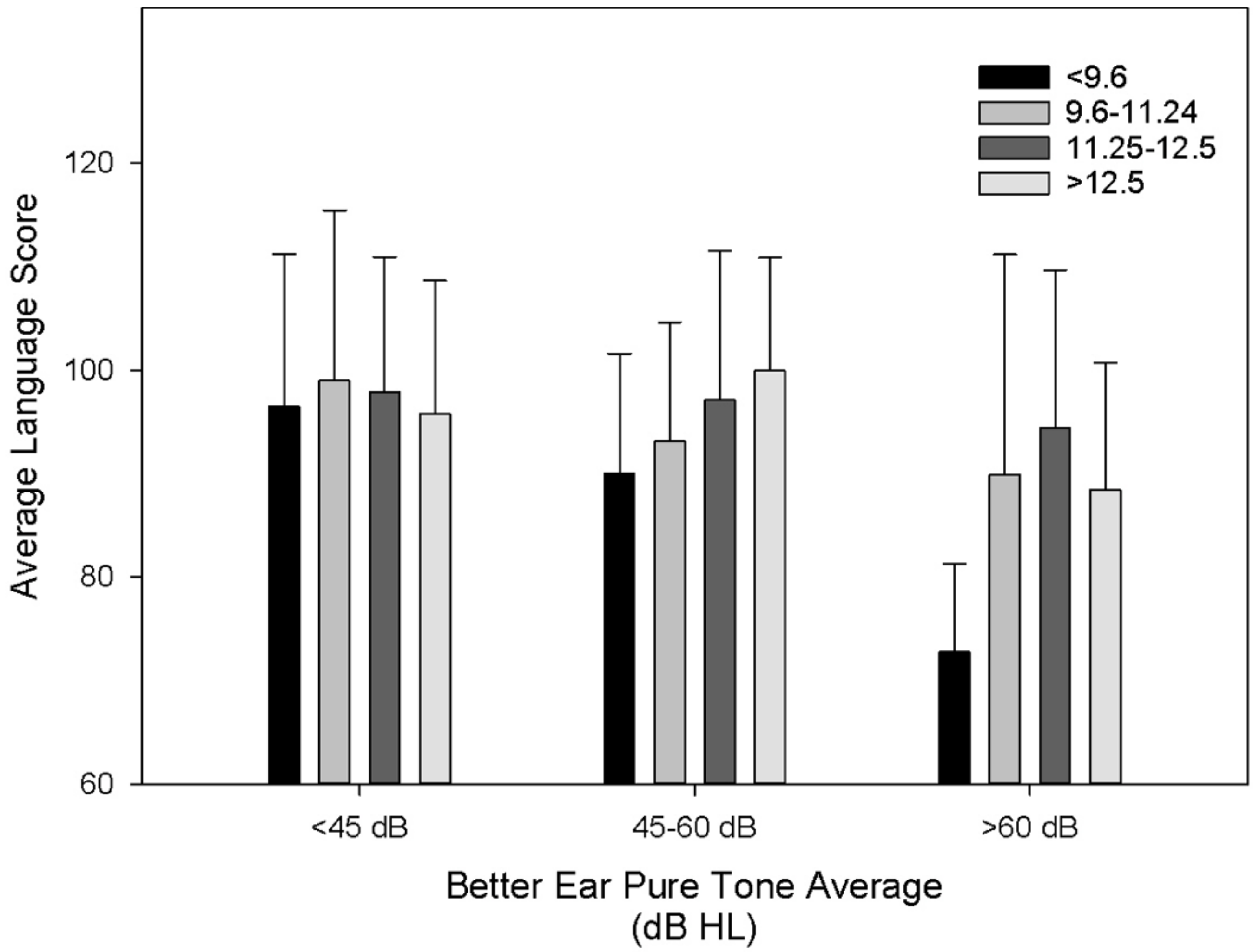

Figure 6.
Average language scores and standard deviations (bars) by unaided hearing severity and average level of use (in hours per day) for children who are hard of hearing grouped according to average better ear pure tone average.

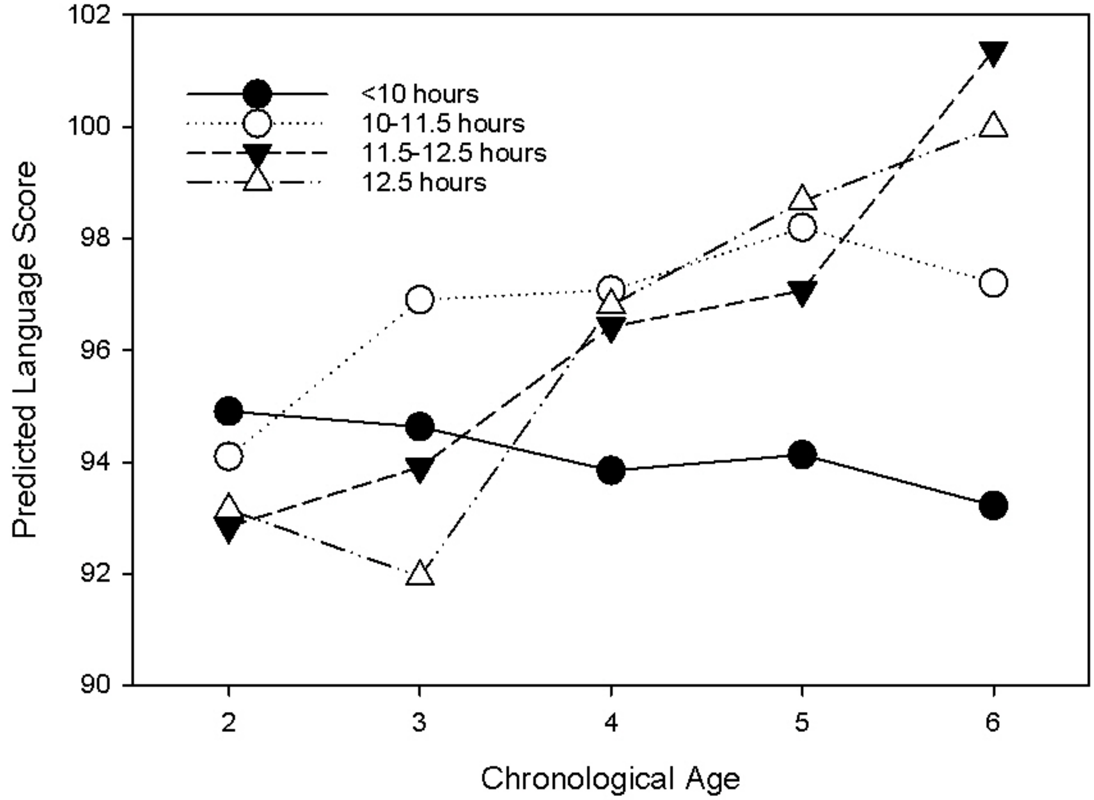

Figure 7.
Average predicted language scores based on mixed model across ages of 2 through 6 years for children who are hard of hearing grouped into four levels of daily hearing aid use.

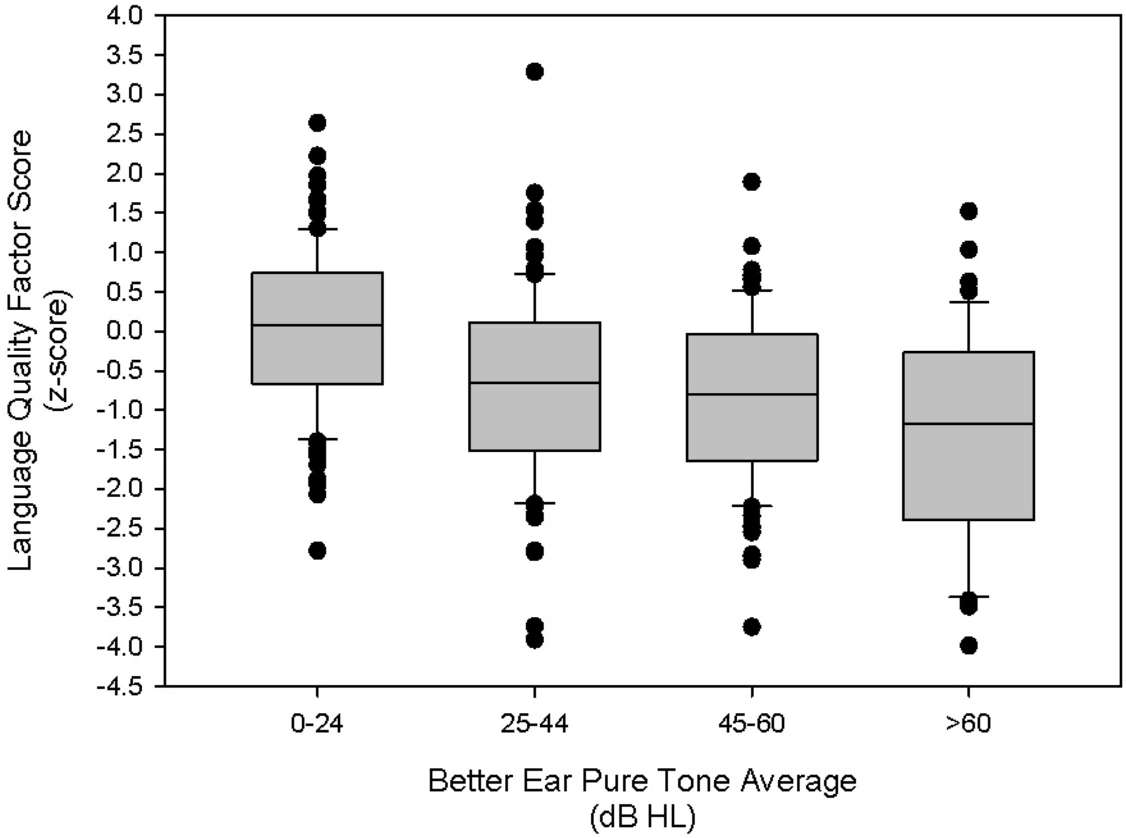

Figure 8.

Box and whisker plots of factor scores for measures of spontaneous language that reflect language quality across levels of pure tone hearing. Boxes represent 25th through 75th percentile and line in box represents the median. Whiskers extend to maximum and minimum values excluding outliers shown as filled circles.

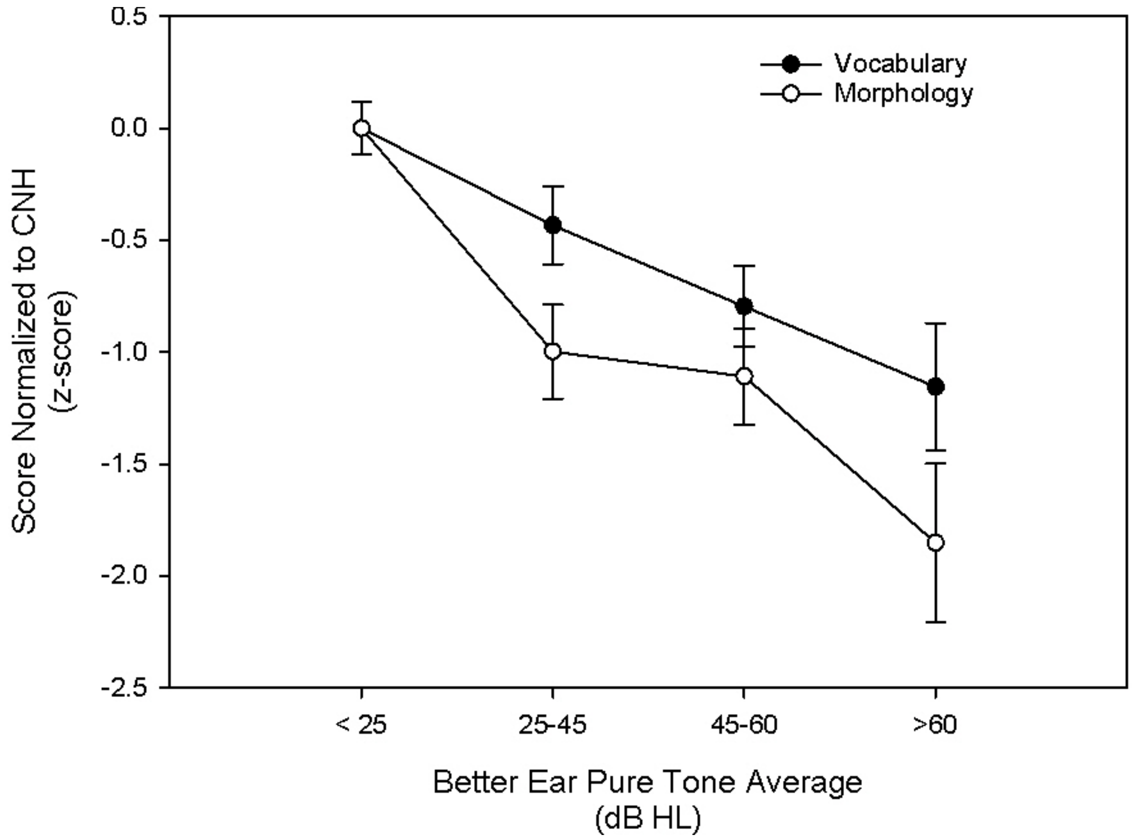

Figure 9.
Mean *z*-scores and standard deviations (bars) for children who are hard of hearing (normalized to children with normal hearing [CNH]) as a function of hearing level for tests of morphology and vocabulary.

Table 1

Norm-referenced, standardized language tests used for analysis of growth from ages 2 through 6.

Year	Tests
2 year	MacArthur Bates Communicative Development Inventories (Words Produced, Sentence Complexity, Word Forms)
	Mullen Scales of Early Learning (Receptive, Expressive)
	Vineland Adaptive Behavior Scales (Receptive, Expressive)
3 year	Comprehensive Assessment of Spoken Language (Core)
	Vineland Adaptive Behavior Scales (Receptive, Expressive)
4 year	Wechsler Preschool and Primary Scale of Intelligence (Vocabulary)
	Comprehensive Assessment of Spoken Language (Core)
	Vineland Adaptive Behavior Scales (Receptive, Expressive)
5 year	Clinical Evaluation of Language Fundamentals – Fourth Edition (Word Structure)
	Preschool Language Assessment Instrument – Second Edition (Receptive, Expressive)
	Peabody Picture Vocabulary Test – Fourth Edition
6 year	Wechsler Abbreviated Scale of Intelligence (Vocabulary)
	Comprehensive Assessment of Spoken Language (Core)

Table 2

Correlations (in italic) between language measures obtained 1 and 2 years after the initial observation. Number of observations are show in parenthesis.

	Wave of Testing			
Wave of Testing	**Three**	**Four**	**Five**	**Six**
Two	*0.81* (117)	*0.79* (71)		
Three		*0.85* (134)	*0.72* (58)	
Four			*0.84* (128)	*0.83* (84)
Five				*0.91* (140)

Table 3

Mean standard scores for the language composite scores for the children with normal hearing (CNH) and children who are hard of hearing (CHH) across the waves of assessment.

Age	CNH			CHH			Between Groups	
	M	***SD***	***n***	***M***	***SD***	***n***	***t* test**	**Cohen's d**
2	105.9	10.62	41	95.37	15.11	116	$t(998.91) = 4.84^{*}$	.75
3	104.1	12.1	54	93.04	13.75	134	$t(186) = 5.17^{*}$	.84
4	106.6	11.18	65	95.42	12.89	148	$t(211) = 6.07^{*}$	.91
5	112.6	12.27	52	98.31	16.38	134	$t(123.1) = 6.46^{*}$	94
6	111.0	12.07	55	97.34	15.91	133	$t(131.64) = 6.41^{*}$	.92

* p<.0001

Table 4

Multilevel model of intercept and growth of language as a function of average better ear pure tone average (Average BEPTA).

Effects	Parameter	df	F (*t*) value	*p* level
Intercept	103.87			
Maternal Education		3,211	18.74	<.0001
<High School	−10.0	1,176	(−3.58)	0.0004
High School	−11.34	1,176	(−6.28)	<0.0001
Some Post Secondary	−4.66	1,176	(−2.61)	0.01
College Graduate	0			
Age	1.0	1,308	10.62	0.001
BEPTA	−0.32	1,211	50.72.	<.0001
Age * Average BEPTA	0.0002	1,211	0	0.99

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Table 5

Multilevel model of intercept and growth of language as a function of average aided residualized SII (Average rSII).

Effects	**Parameter**	**df**	***F*** **(*t*) value**	***p*** **level**
Intercept	101.24			
Maternal Education		3,113	8.70	<.0001
< High School	−6.08	1,113	(−1.40)	0.0004
High School	−11.34	1,113	(−4.88)	<0.0001
Some Post Secondary	−3.17	1,113	(−1.33	0.19
College Graduate	0			
Age	0.65	1,174	2.75	0.10
Average rSII	2.60	1,113	0.02	0.88
Age * rSII	16.09	1,113	7.13	0.009

Table 6

Mixed model of intercept and growth over chronological age of language as a function of age at hearing aid fit.

Effects	**Parameter**	***df***	***F* (*t*) value**	***p* level**
Intercept	121.81			
Maternal Education		1,114	28.84	<.0001
< High School	−7.99	1,114	(−2.09)	0.04
High School	−12.18	1,114	(−5.78)	<0.0001
Some Post Secondary	−3.44	1,114	(−1.55)	0.12
College Graduate				
AveBEPTA	−0.35	1,114	29.65	<.0001
Chronological Age	0.15	1,187	0.08	0.78
Age at HA Fit	−0.34	1,114	12.79	0.0005
Chronologicl Age*Age at HA Fit	0.07	1,114	5.12	0.026

Table 7

Duration of hearing aid use across the waves of assessment for children who were fit at different ages.

Age at HA Fit (months)	Chronological Age (years)				
	2	**3**	**4**	**5**	**6**
<6	21.87	33.74	45.81	57.52	69.84
	(2.07) 49	(2.50) 65	(2.72) 62	2.73) 41	(2.56) 30
6–12	17.48	29.40	41.72	53.47	65.52
	(2.41) 29	(3.27) 38	(2.94) 35	2.87) 32	(1.86) 24
12–18	10.50	23.33	35.00	48.80	60.60
	(3.41) 5	(3.67) 8	(4.50) 11	(2.94) 8	(3.85) 7
>18	7.87	11.86	19.23	22.25	29.71
	(5.3) 11	(6.01) 27	(10.0) 41	(13.09) 55	(13.46) 43

Table 8

Mixed model of intercept and growth over chronological age of language as a function of the amount of daily hearing aid use.

Effects	Parameter	*df*	*F (t)* value	*p* level
Intercept	109.95			
Maternal Education				
< High School	−7.10	102	(−1.74)	0.08
High School	−10.62	102	(−4.62)	<0.0001
Some Post Secondary	−2.13	102	(−0.89)	0.37
College Graduate				
BEPTA	−0.11	1, 102	7.82	0.006
Chronological Age	−2.50	1,179	3.15	0.08
Hours of Daily HA Use	−0.49	1,102	2.35	0.13
Chronological Age*Hours of Daily HA Use	0.31	1,102	6.42	0.013

Table 9

Measure	Factor 1 Language Quality	Factor 2 Language Quantity
Mean number of morphemes in complete intelligible utterances (T units)	93*	14
Total number of utterances produced by the child in sample	10	97*
Number of total words produced by the child in the sample	64*	73*
Number of different words used by the child in the sample	88*	31
Bound morphemes used by the child in the sample	84*	41
Utterances per minute	10	97*
Number of mazed words	68*	29
Number of obligatory words omitted	3	67*
Total Developmental Sentence Score	84*	−9

Table 10

Correlations between standardized language measures at 3 years of age and the language quality (Factor 1) and quantity (Factor 2) measures from the concurrent spontaneous language samples.

	Core	Vineland Receptive	Vineland Expressive	Language Composite
Factor 1	.74	0.44	.64	.70
	$p < .0001$	$p < .0001$	$p < .0001$	$p < .0001$
	126	120	120	130
Factor 2	−0.04	−0.02	−0.04	−0.01
	$p < .18$	$p < .87$	$p < .63$	$p < .0001$
	126	120	120	130

Note. Core refers to the score from the Comprehensive Assessment of Spoken Language.

Table 11

Morphological forms probed in the Morphology Probe task.

	Fraction Missing	Relative Efficiency	Mean %
Plural regular	0.032	0.99	87.4
Plural irregular	0.015	1.0	65.78
Possessive	0.03	0.99	74.10
Third person	0.10	0.98	53.27
Copula be	0.007	1.0	76.56
Regular past	0.04	0.99	53.24
Irregular past	0.17	0.97	42.03
Aux	0.08	0.98	71.66
Progressive	0.03	0.99	91.82

Fraction Missing refers to the proportion of values that were imputed. Relative Efficiency is an indicator of the reliability of the measure after imputation. Mean % refers the mean values for each measure after imputation.