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Aided Hearing Moderates the Academic Outcomes of Children with Mild to Severe Hearing Loss

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Abstract

Objectives—There are very limited data regarding the spoken language and academic outcomes of children with mild to severe hearing loss during the elementary school years and the findings of these studies are inconsistent. None of these studies have examined the possible role of aided hearing in these outcomes. This study used a large cohort of children to examine these outcomes and in particular to examine whether aided hearing moderates the effect of hearing loss with regard to these outcomes.

Design—The spoken language, reading, writing, and calculation abilities were measured after second and fourth grades in children with mild to severe hearing loss (children who are hard of hearing; CHH, $n = 183$) and a group of children with normal hearing (CNH, $n = 91$) after the completion of second and fourth grades. Also, among the CHH who wore hearing aids, aided better-ear speech intelligibility index (BESII) values at the age of school entry were obtained.

Results—Oral language abilities of the CHH with mild and moderate hearing loss were similar to the CNH at each grade. Children with moderately-severe hearing loss (better-ear pure tone threshold > 59 <76 dB HL) had significantly poorer oral language and reading skills than the CNH at each grade. The children with mild and moderate hearing loss did not differ from the CNH in oral language or reading. No differences were found between the CHH regardless of severity and CNH with regard to spelling, passage writing, or calculation. The degree to which hearing aids provided audible speech information played a moderating role in the oral language outcomes of CHH and this moderation of language mediated the relationship between the unaided hearing ability of the CHH and their academic outcomes.

Conclusions—As a group, children with mild and moderate hearing loss have good outcomes with regard to language and academic performance. Children with moderately-severe losses were less skilled in language and reading than the CNH and CHH children with mild and moderate losses. Audibility provided by hearing aids was found to moderate the effects of hearing loss with

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respect to these outcomes. These findings emphasize the importance of including the effects of clinical interventions such as aided hearing when examining outcomes of CHH.

The academic achievement of children with hearing loss (HL) has been a long-standing concern. There is considerable empirical evidence that, as a group, children with HL show poorer academic outcomes than peers with normal hearing. Much of this research has been focused on children with severe and profound HL. This research has shown that children with severe to profound HL are very likely to have long-term academic difficulties, particularly with regard to reading and literacy (see for instance: Holt 1993; Holden-Pitt & Diaz 1998; Mitchell & Karchmer 2011). Unfortunately, in these studies, children with mild to severe HL (referred to here as children who hard of hearing, CHH) were combined with deaf children (severe to profound HL), and thus, the risk for poor academic outcomes of CHH is less clear.

There are several reasons why CHH need to be differentiated from deaf children who have severe or profound HL. CHH have residual hearing that often can be improved via hearing aids and are typically raised in the hearing community with expectations for primary reliance on spoken language for communication. In contrast, children who are deaf usually receive minimal benefit from hearing aids. In recent years, they are often provided with cochlear implants and/or taught communication via sign language. These differences in aural habilitation and communication modality support the need to examine the outcomes of CHH separately from children who are deaf.

Over the last half-century, there have been a small number of studies that have focused on the academic outcomes of CHH. One of the earliest studies was by Kodman (1963) who reported on general academic achievement of 100 school-age CHH. These children were found to have grade-equivalent achievement test scores about 2.5 years below their chronological age and one year below their actual grade placement. Interestingly, Kodman noted that only 35% of these children were wearing hearing aids. Similar results were reported by Quigley and Thomure (1969). In this study, poorer academic outcomes were associated with more severe HL. A similar association was also found by Davis and colleagues (1981) who reported that classroom-based assessments of academic outcomes in children with losses less than 50 dB HL were generally age appropriate. In a follow-up study using individually administered tests, Davis and colleagues did not find an association of hearing severity with educational outcomes and, as a group, the scores of CHH were poorer than expected based on the test norms (Davis et al. 1986). Although the CHH showed risk for poorer academic performance, several of the children were attaining expected levels of achievement, particularly in mathematics. Fifteen years after the Davis research, the next study on academic outcomes of CHH appeared (Briscoe et al. 2001). In this study, 19 children with minimal to moderate sensorineural HL were compared with children with specific language impairment and a typically-developing comparison group. Of the 19 children with HL, 16 had hearing levels better than 40 dB HL. Measures of reading in these children showed levels comparable to the controls with normal hearing. Later Halliday and Bishop (2005) compared a group of children with mild and moderate HL with a group of children with dyslexia and again found the CHH to have age-appropriate reading abilities. A similar study of the literacy outcomes of CHH and children with dyslexia (Park &

Lombardino 2012) compared the literacy skills of 21 CHH with children who were dyslexic along with an age-matched control group of typically developing children. Measures of non-word reading, real-word reading, reading comprehension, and spelling showed the CHH to have poorer scores than the typically developing children. Recently, Camarata and colleagues (2018) examined the relationships of phonological awareness, subjective fatigue, and reading in a group of CHH. This study did not formally compare the reading abilities of CHH with normal hearing age mates; however, their descriptive data suggested an excess of poor readers in the group of CHH. Tomblin and colleagues (2018) reported that despite evidence of being at-risk for poor reading in the preschool years, by second grade CHH were similar to children with normal hearing (CNH) with regard to word reading and only the CHH with moderately-severe HL were poorer than CNH in reading comprehension.

The review above reveals that only a few studies have focused on how well CHH fare in school. The evidence tends to point to some degree of underachievement among these children; however, there are some studies that support normal levels of reading achievement. The clinical management of HL within the U.S. has changed substantially during the past 15 to 20 years. This has principally been due to improvements in universal newborn hearing screening and early identification, hearing aid fitting, and speech and language intervention. Davis et al. (1986) noted that the average age of hearing aid fitting for the CHH with mild to severe HL in their study was 5.24 years. In contrast, more recently, Holte and colleagues (2012) reported that the average age of hearing aid fitting among the children in the Outcomes of Children with Hearing Loss (OCHL) cohort was 10 months. One of the main arguments for newborn screening and early intervention was that these services should improve the outcomes of CHH. In order to address this, over the past 10 years, we have conducted a longitudinal study of the outcomes of children with mild to severe HL (the OCHL study). The preschool outcomes of these children were reported in a series of papers (Moeller & Tomblin 2015; Tomblin, Harrison, et al. 2015; Tomblin, Walker et al. 2013, 2015). We found that the CHH in this study cohort had poorer speech and language development than normal hearing peers; however, early hearing aid fitting and regular daily hearing aid use moderated these effects. These findings underscore the importance of incorporating data on intervention into analyses that are concerned with outcomes of these children. The prior research concerning academic outcomes of CHH had not incorporated audiological intervention data into statistical analyses.

The Effects of Aided Hearing on Oral Language Development and Academic Outcomes

As our research on outcomes of CHH incorporated additional variables concerned with audiologic and educational management, we have found it necessary to build conceptual models that can guide our analysis. The model employed in this study is shown in Figure 1. In this case, we have proposed four classes of variables. The first is the primary independent variable of unaided hearing and this is shown on the far left of Figure 1. The second consists of a set of basic academic skills involving reading, writing, and calculation that represent the ultimate outcomes of interest. These are shown on the far right of the figure. In this model, we have included two classes of variables that intervene between the child's unaided hearing and the academic outcomes. These intervening variables are candidate influencers on the relationship between unaided hearing and academic outcomes.

One of these intervening variables is oral language. In our model, we propose that oral language functions as a mediator between unaided hearing and academic outcomes. A mediator can be thought of as a causal link and in Figure 1 is shown via dashed lines as an indirect path from unaided hearing through oral language to academic outcomes. Considerable support for this mediating role of oral language can be found in studies of CNH where limitations in oral language are associated with poorer academic outcomes (see for instance: Hall & Tomblin 1978; Beitchman et al. 1996; NICHD Early Child Care Research Network 2005; Catts et al. 2008). As we noted earlier, we have reported that the language outcomes of CHH at the point of school entry are poorer than CNH. Thus, we predict that these poorer oral language skills may play an important role in subsequent academic outcomes. In Figure 1, we also show that an alternative to this indirect path is a direct path from unaided hearing to academic outcomes that does not involve oral language. It is possible that both paths carry the effect of unaided hearing to academic outcomes.

The second intervening variable in Figure 1 involves the provision of aided hearing. In this case, we believe that aided hearing through hearing aids functions to improve the child's access to auditory experience and in particular to oral language. Thus, aided hearing can be viewed as reducing the effect of unaided hearing on oral language. In this way, aided hearing functions as a moderator. The moderating effect of aided hearing is shown as acting on both the direct and indirect path and thus altering the strength of the relationship between unaided hearing and academic outcomes. Importantly, the moderating effects of aided hearing may reduce the effect of unaided hearing on language, thereby moderating a mediator. Evidence in support of this moderating role of aided hearing on oral language has only recently been shown. Stiles and colleagues (2012) reported that individual differences in language among CHH were associated with aided hearing abilities. Tomblin and colleagues showed that individual differences in oral language growth during the preschool years were associated with the amount of audible speech provided by the child's hearing aids after controlling for unaided hearing (Tomblin, Harrison et al. 2015).

This moderating effect of aided hearing on the effects of a HL on oral language development is likely to play a critical role in the academic outcomes of CHH due to the importance of oral language to early school achievement. There is considerable evidence that even among CNH, limitations in oral language and phonological awareness are associated with poor academic outcomes (Hall & Tomblin 1978; Beitchman et al. 1996; NICHD Early Child Care Research Network, 2005; Catts et al. 2008). We have recently shown that, when compared with their peers with normal hearing, CHH have poorer oral language and phonological processing skills at the age of 5 years, but do not differ with regard to their knowledge of print (Tomblin et al. 2018). These skills, particularly oral language, were shown to be strong predictors of later reading in CNH and in accord with this, we demonstrated that the early literacy skills of the CHH placed them at-risk for later reading problems. Despite this risk, we found that the CHH after second grade were not different from CNH with regard to nonword and real word reading skills and this relationship extended to reading comprehension, except for the CHH with moderately-severe HL. In light of these initial findings, we have expanded our model concerning the moderating effects of hearing aids on oral language to predict that this moderation of oral language also then serves as an intervening variable that links the effects of aided and unaided hearing with academic outcomes.

Based on this conceptual framework, this study addressed three questions:

1. Are oral language, reading, spelling, writing, and calculation associated with variation in unaided hearing levels in CHH in second and/or fourth grade? This question simply asks how these CHH are doing in second and fourth grades and allows us to compare our findings with the prior studies.
2. Does aided hearing moderate the effect of unaided hearing on oral language in second and fourth grade?
3. Does oral language mediate the association between unaided hearing and academic outcomes in second and fourth grade?

Method

Participants

The 274 children in this study were all participants in a large-scale longitudinal study of outcomes of children with HL. Most of these children ($n = 198$) had been followed throughout the preschool years as a part of the OCHL study (Moeller & Tomblin 2015). This study used an accelerated longitudinal design wherein children were recruited between the ages of 6 months to 7 years of age and were followed prospectively on an annual basis during the preschool years. Toward the end of the OCHL study, we obtained funding to continue to follow these children through fourth grade by examining their academic abilities after second grade and fourth grade (Outcomes of School-Age Children who are Hard of Hearing; OSACHH). Because of the accelerated longitudinal design, some of the original children had already passed through the second or fourth-grade assessment windows and were not able to participate in the OSACHH study. To compensate for the loss of these children, we recruited an additional 76 children for the OSACHH study. Children with developmental disabilities and children who communicated via sign language or had received cochlear implants were not maintained in the cohort to allow examination of outcomes that are specific to children with mild to severe HL.

The CHH ($n = 183$) in this study were required to have bilateral HL between 25 and 75 dB HL in the better ear upon study entry. The median age of identification of the HL for the CHH was 5 months and 75% of these children had been identified by 37 months of age. Of the 43 CHH identified after 37 months of age, 34 had mild HL. Among the CHH all but 6 were fitted with hearing aids and the median age of hearing aid fitting was 8 months. None of the CHH received cochlear implants. Thus, the CHH in this study had HL early in life and most had been provided with early intervention.

To provide a comparison sample of CNH, we also enrolled 91 controls with normal hearing with similar home backgrounds in terms of household income and parental education. They were recruited from the same catchment areas as the CHH. CNH also had no additional disabilities and communicated using spoken English.

Participation by Grade

Second grade—We obtained data on 226 children (49% girls) seen during the summer months after they had completed second grade. Of these children, 170 were also participants in the Tomblin et al. (2018) study concerned with preschool risk factors for reading. At the second-grade testing wave, the children averaged 8.49 years (*SD* = 0.36) of age. Seventy-nine children had normal hearing (CNH) and 147 were CHH. The CHH were categorized based on degree of HL: mild (<45 dB HL, *n* = 69), moderate (45–59 dB HL, *n* = 49), and moderately-severe (60–75 dB HL, *n* = 29). Table 1 provides the distribution of the educational levels of the mothers of these children. The median educational level of the mothers was an undergraduate college degree. Thus, the samples were generally biased toward better-educated families. When mothers were categorized into high school, post-secondary attendance, college graduate, or post-graduate levels of education, a Wilcoxon rank sum test across the subgroups including the CNH did not support a significant difference in maternal education level, $\chi^2 = 4.75$, $df = 3$, $p = .19$.

Fourth grade—We obtained data on 198 children at the end of fourth grade (51% girls). Of these, 150 children had also participated after second grade. At this assessment wave they averaged 10.41 years (*SD* = 0.37) of age. Sixty-nine were CNH and 129 were CHH (mild = 67, moderate = 37, moderately-severe = 25). As in second grade, the four subgroups of children did not differ with regard to the median educational level of the mothers $\chi^2 = 1.53$, $df = 3$, $p = .67$.

Measures

The language and academic status of the children in this study was assessed by a set of norm-referenced standardized tests obtained after completion of second and fourth grade. Standard scores were derived from the test manual based on the child's age for the measures of grammatical and narrative abilities and based on grade placement for all other measures.

Oral language—A battery of measures of oral language was employed at each grade. Each battery contained a common measure of vocabulary using the Picture Vocabulary test of the Woodcock-Johnson III Tests of Achievement NU (WJ III; Woodcock et al. 2007). Each battery also contained a measure of grammatical ability. In second grade, this test was the Clinical Evaluation of Language Fundamentals-4 (CELF-4) Word Structure subtest (Semel et al. 2004) which measures morphological ability by asking children to look at a picture and complete a sentence, using correct morphological endings. The CELF-4 battery employs a different measure of grammar at the fourth-grade level due to ceiling effects of the Word Structure subtest. This test was the Formulated Sentences subtest, which prompts children to generate sentences that are semantically and grammatically correct in response to pictures and assigned words. The second-grade language battery also provided a measure of narrative ability via the Test of Narrative Language Ability (Gillam & Pearson 2004) which is designed to measure children's ability to understand and tell stories in response to pictures and verbal cues. Children also answer comprehension questions following selected spoken paragraphs to yield a narrative comprehension score. The fourth-grade battery included the WJ III Understanding Directions test, which requires children to look at a picture and follow directions presented in a recorded audio format.

Although these measures focus on different aspects of language, a number of studies have shown that measures such as these are largely reflective of a single underlying trait. We examined the dimensionality of each of the two batteries using a principal component analysis and found high levels of communality for the measures in second grade $h^2 > .65$ and fourth grade $h^2 > .68$. We also inspected the correlation structure among these measures within each of the hearing level subgroups and did not find evidence that this structure differed according to hearing status. Therefore, for the purposes of this study, we computed an average language standard score at each grade level.

Reading—All children seen at the end of second grade or fourth grade were tested for reading ability. Three aspects of reading were directly tested using individually administered standardized tests. Non-word decoding ability was measured by the use of the Word Attack test of the WJ III (Woodcock et al. 2007). This test requires the child to read pronounceable nonwords. Reading was also assessed using the Gray Oral Reading Tests-5 (GORT-5; Wiederholt & Bryant 1992) which yielded fluency and comprehension scores. This test asks the child to read a passage orally and scores the child's performance on the accuracy of word decoding and speed of reading. These scores are combined into a measure of reading fluency. This measure of reading fluency provides information about the child's reading of real words contained in natural language passages. The GORT-5 also includes comprehension questions that are asked after the child has read the passage and the answers serve as a measure of reading comprehension. Together, the GORT-5 and WJ III provided two measures of word reading (accuracy and fluency for reading real words and decoding of nonwords, respectively, and one measure of reading comprehension).

Spelling and writing—Spelling and writing were assessed via the Spelling and Writing Samples tests of the WJ III. The Spelling test asks the child to spell orally presented words. The Writing Samples test measures skills in writing meaningful passages after being given a verbal and picture cue. Written sentences produced by the child are evaluated concerning the quality of expression, but not the accuracy of punctuation or spelling.

Mathematics calculation—The Calculation test of the WJ III was used to measure the children's skills at writing numbers and performance on addition, subtraction, multiplication, and division.

Hearing status—Pure-tone audiometric thresholds were obtained from children in this study at each observation wave. For this study, unaided hearing was calculated using the average unaided pure tone threshold at 500, 1000, 2000, and 4000 Hz and the average in the better ear was used to represent better-ear pure-tone average (BEPTA). Also, we obtained aided hearing ability in the form of an aided speech intelligibility index in the better ear (BESII) score from those children who were wearing hearing aids. The aided SII provides a measure of the weighted proportion of the speech spectrum that is made audible by the hearing aid. SII scores range from 0, meaning no audibility or access to speech sounds, to 1, meaning full audibility (see Tomblin, Walker et al. 2015 for more information on SII). Although aided SII is highly correlated with unaided PTA and unaided SII, we have shown that aided SII contributes unique information with regard to children's language development over and above these measures of unaided hearing (Tomblin, Harrison et al. 2015). For this study, the hearing status for the CHH and CNH at the age of five or six was used for the 198 children who had participated in the OCHL study. For the 76 children who had not been in the OCHL study, their average aided and unaided hearing obtained after second and fourth grade were used. Details of the audiometric methods are provided in our prior publications (McCreery et al. 2015).

Results

Our analyses of the data were guided by the model shown in Figure 1 and the questions posed in the introduction. To address our first question we examined the relationships between unaided hearing status and the second- and fourth-grade outcomes in the areas of language, reading, spelling, writing, and calculation. Thus, this analysis was aimed at describing how the CHH were doing in the early school years. We will show that with the exception of reading in the CHH with moderately-severe unaided HL, the achievement of the CHH was comparable to the CNH. These findings could be interpreted as demonstrating that mild and moderate HL is benign and only moderately-severe losses threaten reading. The second analysis challenges this conclusion by recognizing that most of these children had been wearing hearing aids, thus their auditory functioning is not well represented by their unaided hearing. Guided by question 2, we examined the portion of the model concerned with whether aided hearing ability, as indexed by BESII, played an important role in modifying the relationship between unaided hearing and oral language. We will show that the degree to which the CHH had audible hearing via hearing aids interacted with their unaided hearing. The degree of unaided hearing was not associated with language abilities among those with good audibility, but it was associated with language abilities for those with low levels of audibility. Finally, guided by question 3, we test whether this moderating effect of unaided hearing by aided hearing on language ability, subsequently influences, that is mediates, the reading, writing, and calculation outcomes of the CHH. We will show that there is support for this moderated mediation of unaided hearing by the effects of aided hearing on language onto reading and writing but not calculation.

Question 1: Are Oral Language and Academic Outcomes Associated with Variation in Unaided Hearing Levels in CHH at Second and/or Fourth grade?

Each of the language and academic outcomes were examined with respect to whether these outcomes differed as a result of the child's unaided hearing level where hearing level was treated categorically based on BEPTA: normal (<20 dB HL), mild (20–45 dB HL), moderate (45–59 dB HL) and moderately-severe (60–75 dB HL). The mean standard score and standard deviation for each of the outcome measures at each grade for the children grouped according to these categories of hearing status are shown in Table 2 and the distribution of the scores are shown as box plots in Figures 2–4. We employed a linear mixed model analysis (LMM) to test the main effects of hearing status and grade-at-testing, as well as, their interaction. Each of these was treated as a fixed effect with a random intercept for subject and a random slope for grade. In those cases where the main effect of hearing level category was significant, follow-up tests were performed to determine which hearing level contrast contributed to the significant main effect. In these cases, the significance tests were corrected for multiple testing via a Tukey-Kramer correction method. In these analyses, the mother's educational level was not included, because it was not associated with the independent variable of hearing level. Table 3 provides the summary results of the LMM analyses for each of the outcome variables.

Oral language—As noted in the Methods, the three oral language scores at each grade level were averaged to represent oral language abilities in these children. The LMM analysis showed a significant effect of hearing level, but no significant grade effect or interaction. Follow-up tests involving comparisons of language ability among the levels of HL showed that the children with moderately-severe HL were significantly poorer than each of the other subgroups: CNH, $t(269)= -5.20$, $p <.0001$, mean difference = −11.56; children with moderate HL, $t(269)= -4.53$, $p < .0001$, mean difference = −10.52, children with mild HL, $t(269) = -3.18$, $p = .01$, mean difference = −7.15. Also the CHH with mild HL were poorer than the CNH, $t(269) = -2.79$, $p < 0.03$, mean difference = −4.41. The CHH with moderate HL were not different from the CNH. Thus, the children with mild and moderately-severe HL were poorer than the CNH in both grades, whereas the CHH with moderate loss were comparable to the CNH concerning oral language in both grades. This pattern shows a non-linear relationship between HL and language such that the children with moderate HLwere doing better than those with mild HL.

Reading

__**Word attack:**__ The upper panel in Figure 3 shows the distribution of scores across grades and unaided hearing level for Word Attack. The LMM applied to the measure of Word Attack yielded a significant effect of hearing status and grade, but no significant interaction between these variables. The significant main effect of grade reflected average standard score values for second grade being 2.39 ($SD = 10.02$) greater than those in fourth grade. A follow-up analysis of the significant effect of hearing level showed that the children with moderately-severe HL were significantly poorer than the other subgroups: CNH, $t(269) =-3.51$, $p = .003$, mean difference = −7.08; children with mild HL, $t(269) = -3.78$, $p = .001$, mean difference = −7.72; children with moderate HL, $t(269) = -4.53$, $p < .0001$, mean difference = − 9.55. None of the contrasts between the CNH and the children with mild or moderate HL were statistically significant. Thus, only children with moderately-severe HL were poorer than the CNH.

__**Fluency:**__ The distribution of scores for the Fluency test are shown in the middle panel of Figure 3. The LMM analysis of the measure of reading fluency provided by the GORT-5 revealed a significant interaction between hearing level and grade, which necessitated separate tests of the hearing level effects for each grade. For second grade, we found a significant effect of hearing level, $F(3,216) = 3.99$, $p < .0001$. Follow-up tests with revealed significant differences between the children with moderately-severe HL and each of the other subgroups: CHH, $t(216) =- 3.15$, $p = .01$, mean difference = −9.27; children with mild HL, $t(216) = -3.03$, $p = .01$, mean difference = −9.22 ; children with moderate HL, $t(216) =$

−3.25, $p = .007$, mean difference =− 9.91. No other differences were statistically significant. The test for hearing level differences for reading fluency after fourth grade was not significant. Thus, children with mild or moderate HL have real word reading abilities that are similar to CNH across grade levels. The children with moderately-severe HL were less skilled at word reading than the other groups in second grade, but this difference did not remain at fourth grade.

Comprehension: The bottom panel of Figure 3 shows the distribution of scores for the reading comprehension measure across grades and unaided hearing level. The LMM analysis of reading comprehension measured by the GORT-5 indicated no significant effect of grade, but a significant effect of hearing level. The interaction between grade and hearing level was also not significant. Follow-up tests of the significant hearing level main effect showed that the CHH with moderately-severe HL were again significantly poorer than the children in the other subgroups: CNH, $t(264) = -4.28$, $p = .0002$, mean difference = −11.37; children with mild HL, $t(264) = -3.15$, $p = .01$, mean difference = −8.51; children with moderate HL, $t(264) = -3.64$, $p = .002$, mean difference = −10.09. The children with mild and moderate HL were not different from the CNH.

Spelling—The top panel of Figure 4 presents the results of the Spelling test of the WJ III. An LMM analysis of these data indicated that there was a significant main effect of hearing level, $F(3,269) = 3.37$, $p = .019$. There was a significant grade effect, $F(1,146) = 25.71$, $p < .0001$ with a difference of 4.24 standard score units in favor of the children in fourth grade; however, there was no significant interaction between hearing level and grade. Follow-up tests showed that only one contrast was significant: children with moderate HL displayed significantly better spelling than children with moderately-severe HL, $t(269) = 3.09$, $p = .013$, mean difference = 10.32. No other contrasts were significant. Thus, we can conclude that the CHH, as a group, were not different than the CNH. As found in some of the other measures, the children with moderate HL had nominally better (4.81) spelling scores than the CHN and nominally better (3.96) spelling scores than the children with mild HL along with their significantly better (10.31) spelling scores than the children with moderately-severe HL. Thus, again, there is a suggestion of a nonlinear relationship between unaided hearing and spelling where the CHH with moderate HL seem to be doing particularly well.

Writing—The middle panel of Figure 4 provides the summary scores of each of the subgroups on the Writing Samples test of the WJ III. An LMM analysis of these data showed a significant effect of hearing levels, but no significant grade effect nor significant interaction of these. A follow-up comparison of the hearing level main effect revealed a pattern of results that was similar to Spelling. The children with moderate HL showed significantly better scores than the children with moderately-severe HL, $t(267) = 2.79$), $p = .03$, mean difference = 6.60; however, none of the contrasts between the CNH and the CHH were significantly different. Therefore, the writing quality of the CHH, in general, is comparable to those of the CNH. Again, we did find that the children with moderate HL were nominally better than the other subgroups of CHH.

Mathematics calculation—The bottom panel of Figure 4 presents the summary statistics of the subgroups about their performance on the Calculation test of the WJ III. The LMM analysis showed no significant hearing level effect, grade effect, nor a significant interaction between these. Thus, all subgroups of children with varying unaided hearing levels were comparable concerning their basic mathematical calculation abilities at both grade levels.

Summary of question 1 findings—These results show that language and academic outcomes among CHH vary across severity of HL and domains of language and academic function. Among the CHH, those who had moderate HL showed outcomes that were comparable to CNH in all areas. We also noted that these children were nominally better than the CNH on the two measures of word reading as well as spelling. Additionally, children with moderate HL were usually significantly better than the children with moderately-severe HL. A similar pattern of comparable outcome relative to the CNH was found for children with mild HL except with regard to oral language, where they were significantly poorer than the CNH. Also, despite their better unaided hearing these children frequently had nominally poorer outcomes than the children with moderate HL. These generally good outcomes for these children with moderate HL in the school years contrasts with evidence we have shown that these children were at risk for poor outcomes at school entry (Tomblin et al. 2018). The children with moderately-severe losses often performed below the CNH in the areas of oral language and reading, thus in these children we see less resilience. However, even for these children with moderately-severe losses, normal levels of written language and calculation were found. These results could be used to argue that mild and moderate HL and to some extent moderately-severe HL does not threaten the outcomes of CHH and thus is benign. However, we argued in the introduction that many of these children, even the children with mild HL, were wearing hearing aids. Thus, the good outcomes we find may be due to the benefits of improved audibility provided by hearing aids. This hypothesis was tested in Question 2.

Question 2: Does Aided Hearing Moderate the Effect of Unaided Hearing on Oral Language in Second and Fourth Grade?

The data examined in Question 1 tested the relationship between unaided hearing and language and academic outcomes. As shown in our conceptual model we hypothesize that aided hearing plays a moderating role by influencing oral language which in turn influences the academic outcomes. Question 2 focuses on whether the relationship between unaided hearing status and language was dependent upon the child's aided hearing.

Methodological preliminaries—With regard to Question 1, we saw that there was no grade effect or interaction between grade and hearing level for oral language. As we noted earlier, most of the children were seen at each grade; however, some were only seen at second or fourth grade. Question 2 calls for statistically testing an interaction between unaided and aided hearing. Tests of interaction place considerable demand on statistical power and thus sample size. As a result we wanted to, where possible, include all the children for whom we had appropriate data. Since we did not have evidence of a grade effect, we averaged the scores for those children with two observations. For those where we only had a score at one grade we used that score in this analysis. Also, our prior research has

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shown that socioeconomic status represented by mother's education is associated with age of hearing aid fitting and use (Holte et al. 2012; Walker et al. 2013). Therefore, in these analyses, we included mother's education as a covariate.

We employed the conditional process analysis framework (Hayes 2018) in order to test the model shown in Figure 1. We used the Process Macro within SAS (Hayes 2018). In this analysis, moderation is measured by the strength of interaction of unaided hearing level as a continuous variable (BEPTA) and aided hearing (aided BESII) when the outcome measures are regressed on these variables. Because this analysis was concerned with the influence of hearing aids, the CNH and the 6 CHH who did not wear hearing aids were excluded from the analysis.

The analysis of the moderation of oral language by aided hearing was conducted using multiple regression of language on unaided BEPTA and aided BESII. The results of this analysis are shown in Table 4. The overall model accounted for 49% of the variance of language. In this analysis, moderation of unaided hearing by aided hearing is tested by the interaction term (BEPTA*aided BESII) which was significant, $F(1, 174) = 31.39$, $p < .0001$. The inclusion of this interaction in the model added an additional 14% of the variance. This interaction term represents the moderation of the effect of BEPTA by aided BESII on language.

Insight into the nature of this moderating effect can be seen in Figure 5. The top panel in this figure displays the relationship between BEPTA and language at three levels of aided BESII. These levels represent the 16^{th}, 50^{th}, 84^{th} percentiles of aided BESII in the cohort of CHH. We can see that at a low level of aided BESII (0.65), language abilities decrease as the degree of HL increases. Thus, variance in BEPTA is negatively associated with language at this level of audibility. In contrast, at the 50^{th} percentile of aided BESII (0.83), variance in BEPTA is no longer associated with oral language. Finally, at high levels of aided BESII, variance in BEPTA becomes positively related to language. This plot shows that the slope of the relationship changes from negative to positive as aided BESII increases.

The bottom panel in Figure 5 shows the relationship of this change in slope across values of aided BESII. This plot allows us to identify the regions of aided BESII where language outcomes are related to unaided BEPTA (significant negative slopes) versus the region of aided BESII where unaided BEPTA is no longer significantly related to language. The boundary of these two regions lies around an aidedBESII value of 0.70. Below this point, the slope of the association of unaided hearing and language is significantly greater than 0. Between values of 0.70 and 0.93 unaided BEPTA is not associated with language. Finally, there is a small region above aided BESII values of 0.93 where, paradoxically, increments in degree of HL are associated with better language. This paradox may be due to our use of a linear model for these slope changes when in fact, the relationship is nonlinear in this region. When we inspect the distribution of children according to the severity of unaided hearing in each of these domains, we find clear differences. The children with moderately-severe HL are largely (85%) found in the region with aided BESII values below 0.71. In contrast, only 16% of the moderate group was in this region and the rest were in the middle region (aided BESII = 0.71 – 0.93). Only 2% of the children with mild HL were in the region below 0.71

and the remainder were in the middle region (67%) or the region with aided BESII values above 0.93 (31%). The children with mild HL were the only children with aided BESII values in a region above 0.93.

In the analysis above we showed that aided hearing moderates the effect of unaided hearing on language. As we show in Figure 1, it is possible the moderation of unaided hearing by aided hearing could affect the academic outcomes directly. We tested this possibility using the same analytic method as we used for moderation of language where the interaction of unaided BEPTA with aided BESII provided the test of moderation. Across all the academic outcomes we did not find evidence of aided BESII having a significant moderating effect on the direct pathways, reading: $F(1,173) = 0.90$, $p = .34$; $\beta = -0.2096$; writing: $F(1,173) = 0.31$, $p = .58$, β, $= -0.1239$; calculation: $F(1,172) = 3.68$, $p = .06$, $\beta = -.80$.

Summary of question 2 findings—The moderation analysis supports the hypothesis that the audibility provided by hearing aids alters the relationship between unaided hearing and oral language development. At low levels of audibility represented by aided BESII language outcomes are associated with variation in unaided hearing level. At higher levels of aided BESII, the association between unaided hearing and language ability no longer holds. We assume at this point, the hearing aid provides enough speech information to benefit language development. We also showed that aided hearing does not appear to moderate academic outcomes directly. Thus, we hypothesize that if aided hearing benefits academic outcomes this benefit will depend on oral language. That is, that oral language served as a mediator of these benefits. This hypothesis is tested in Question 3.

Question 3. Does Oral Language Mediate the Association Between Unaided Hearing and Academic Outcomes in Second and Fourth grade?

The analysis above showed that aided hearing served as an effective moderator of the effects of unaided hearing on oral language development. As we noted in the introduction and in the conceptual model, we believe this moderation of oral language has an important influence on academic outcomes and provides the means for aided hearing to moderate academic outcomes. For this analysis, we simplified the number of academic outcome measures to reduce the number of separate tests. Three academic outcomes were formed: 1) a composite reading measure based on the average of the three reading measures, 2) a composite written language measure formed from the Spelling and Writing Samples tests, and 3) the Calculation test. These were then averaged over grades. As in the analysis of moderation, we included mother’s education as a covariate to control for the effects of home environment within this model.

Moderated mediation of reading—The results of this analysis are shown in the second panel of Table 4 along with the earlier moderation results shown in the top panel. In this case, we see that there was a significant effect of BEPTA on reading, supporting a small direct effect that is neither moderated by aided BESII nor mediated by language. Importantly, the effect of oral language on reading was also significantly associated with reading and as shown earlier, this effect is moderated by the interaction of aided BESII on BEPTA. Hayes (2018) showed that the product of these two terms (effect of language on reading and the effect of the interaction between aided hearing and language) yields an index of moderated mediation. In this case, this index is 1.11. The Process program provides a 95% confidence for this point estimate using a bootstrap method. This confidence interval was 0.55–1.58 which excluded 0. These findings support the moderated mediation process that includes both aided BESII and language. The moderation process provides for aided audibility reducing the effect of unaided hearing loss on oral language. This moderation process then mediates the relationship between unaided hearing loss and reading.

Moderated mediation of writing—The same analysis was run to test the moderated mediation effects of language on writing. As we might expect, the results for writing were very similar to those of reading. The direct effect of BEPTA on writing was not significant, but the indirect effect represented by the moderation of language by aided BESII was significant. The index of moderated mediation was 1.10 similar to that of reading (95% CI = 0.55–1.58).

Moderated mediation of calculation—The test for indirect effect mediated by language was also significant and the direct effect of BEPTA on calculation was not significant. The index of moderated mediation of 0.91 was somewhat lower than that for reading and writing.

Summary of question 3 findings—These analyses show that the relationships between unaided hearing (BEPTA), aided hearing (aided BESII), oral language, and the three academic skills of reading, writing, and calculation are similar. The effects of unaided hearing on oral language are moderated by the degree to which the child's hearing aid provides access to the acoustics of speech indexed by aided BESII. The resulting moderated language ability has a significant effect on the child's academic performance.

Discussion

This study serves as one of the largest contemporary examinations of the language and academic outcomes of children with mild to severe HL during the initial years of school. It is the first to examine the effects of aided audibility provided by hearing aids on these outcomes. We will first discuss our findings regarding these outcomes as a function of unaided hearing. Next we will consider how aided hearing plays a role in these outcomes.

Language and Academic Outcomes and Unaided Hearing Status

For CHH, this study revealed a pattern of outcomes in which oral language and reading were more challenging than spelling, writing, and calculation. As we might expect, this pattern did not apply to all CHH. The pattern accurately describes the children with moderately-severe HL and to some degree those with mild HL; however, it does not apply to children with moderate HL. Thus, we see a non-linearity in the relationship between unaided hearing and these outcomes. Interestingly, when the participants in this study were preschoolers, we did not see this nonlinearity with respect to oral language or phonological awareness (Tomblin et al. 2018; Tomblin, Harrison et al. 2015).

The mixed findings of this study may help address discrepancies in the past literature. Several studies have reported poorer academic outcomes among CHH (Kodman 1963; Quigley & Thomure 1969; Davis et al. 1981; Park & Lombardino 2012); however, others have reported age-appropriate academic abilities (Briscoe et al. 2001; Halliday & Bishop 2005). These studies did not consider the degree of HL in their analysis, and hearing loss was treated as though it was a homogeneous condition. In some cases the sample only involved children with mild and moderate HL, or children with mild losses were combined with those with more severe losses. Our findings underscore the variability in outcomes across the range of unaided hearing loss. Furthermore, this variability is not a simple linear function of unaided degree of hearing loss. Thus, researchers examining outcomes of CHH need to recognize that their findings cannot generalize outside the hearing loss levels of participants in their study.

Another feature of the past literature has been the lack of a control group of CNH. If we had used the test norms as the basis of comparison rather than our control group of CNH, we would have found more CHH within the average range of performance. We also would have found differences between tests that would incorrectly suggest that some areas of performance were differentially associated with HL. For instance, the scores from the GORT-5 were generally lower than those from the WJ III; however, this pattern was shown in the CNH as well. Thus, this variation is likely due to differences in the norm reference groups. An important feature of our control group of CNH was that we controlled for home background. Using mother's education as an indicator, we showed that even with efforts to recruit widely, our sample of CHH was biased toward well-educated homes. This likely explains why the CNH often averaged 10 standard score points above the test mean and why most of the CHH scored well into the average range of the test norms.

Implications—These findings show that with early management of hearing loss, mild and moderate HL does not threaten academic outcomes, at least during the first four years of school. We are less sanguine about the outcomes of the CHH with moderately-severe losses. Despite good outcomes for spelling, writing, and calculation, these children, as a group, seem to be challenged in oral language and reading. This study was focused on basic academic skills, but educational attainment also involves learning in content areas such as social studies and science. Children with limitations in oral language and reading are likely to struggle with social studies and science, because these subjects rely on language and literacy skills.. Therefore, service providers who are working in educational environments need to monitor the educational progress of children with moderately-severe HL.

Aided Hearing Moderates Oral Language Development

Another feature of the prior research with CHH has been the lack of consideration of the effects of aided hearing on outcomes. Several studies, particularly those conducted in the last two decades, have reported age-appropriate language and reading outcomes. Such findings are less common in the research conducted in the prior century. However, one difference between the children in early studies and more recent studies has been the provision of early intervention services, including the early provision of hearing aids. Among the CHH in this study all but 6 children had been fit with hearing aids during the preschool years, and most of these children were fit during their first year of life. Hearing aids increase access to the speech spectrum. Thus, we hypothesized that aided audibility moderates the child's unaided hearing levels by increasing opportunities for language learning throughout the preschool years. Increased access to language learning opportunities is critical because oral language serves as a foundational skill for academic performance.

We explored the hypothesis that aided audibility moderates unaided hearing levels by employing a moderation test (see Figure 1). This moderation test provided strong support for our hypothesis: variation in oral language skills in the school years was associated with an interaction of unaided hearing and aided hearing levels around the time of school entry (around 5 years of age). We also tested whether aided hearing directly modified the effects of unaided hearing on the academic outcomes of reading, spelling, writing, and calculation. This analysis showed no moderation effect of amplification on these outcomes directly. That is, the effects of aided hearing required the mediation of oral language on academic performance. The results for academic outcomes were surprising because we might assume that better audibility would have a general effect on learning. Instead, we found the benefits of better audibility were concentrated on oral language development.

Implications—Our finding that variation in audibility moderated the impact of unaided HL on language has important implications for hearing aid fittings. When hearing aids provided children with more than 71% of the speech spectrum (i.e., aided BESII), variation in unaided hearing was no longer negatively associated with language outcomes. In contrast, children who are provided with aided BESII less than 71% of the speech spectrum continued to show an effect of their unaided hearing on language.

We should emphasize that it would be incorrect to assume that aided hearing below 71% means that this level of aided hearing is ineffective. A more appropriate conclusion is that aided hearing at these levels only partially moderates the unaided hearing and this partial moderation declines with lower levels of aided BESII. We also should clarify that variation in aided hearing above 71% should not be viewed as unimportant. We are not suggesting that 71% represents the ideal aided BESII value. Rather, the data show that as aided BESII increases above this level, the probability that unaided hearing continues to affect language further declines. Thus, for any two children, the child with better aided SII will have a greater probability that language abilities will not be affected by the HL.

These findings provide further support for the value of aided hearing for spoken language development in CHH. They emphasize the importance of consistent use of well-fitted hearing aids that give the child as much speech information as possible. We saw that achieving optimal hearing aid fittings was more challenging for children with moderately-severe losses. As hearing levels increase toward the severe range, increases in amplitude of speech provided by the hearing aid no longer compensate for the HL, due extensive cochlear pathology and reduced dynamic range of hearing (Bagatto et al. 2010; McCreery et al. 2015). For this reason, cochlear implants may become a consideration.

Moderated Oral Language Development Mediates Academic Outcomes

As shown in Figure 1, unaided hearing can either act directly on academic achievement indirectly on academic outcomes. The indirect path shown involves two processes. A moderating process, as discussed above, in which the improvded audibility provided by aided hearing reduces the effect of unaided hearing loss on oral language and a mediation process in which this oral language serves as a causal link between unaided hearing and academic outcomes. Thus, we tested whether the indirect path, representing moderated mediation, was able to explain more variance in academic outcomes than the direct path. Overall, we found support for moderated mediation of academic outcomes. The results were largely similar across the domains of academic outcomes; however, we will discuss each of these separately.

Reading—Our statistical analysis provided support for a moderated mediation model of unaided hearing on reading by oral language. Specifically, most of the effects of unaided hearing on reading involved the moderation of oral language by aided hearing and that this moderated language status then served to link or mediate the relationship between unaided hearing and reading. We also saw a small direct effect of unaided BEPTA on reading. The effect of oral language on reading is consistent with research on reading development in CNH. Several decades of research have provided strong evidence for the importance of oral language as a foundational skill for reading development (Catts et al. 1999; NICHD Early Child Care Research Network 2005; Kendeou et al. 2009; Scarborough 2009). Other skills (e.g., knowledge of letters and print concepts and awareness of sub-lexical sound composition of words) have also been shown to be important to reading, particularly decoding (Storch & Whitehurst 2002); however, even these skills are influenced by oral language (Dickinson et al. 2010; NICHD Early Child Care Research Network 2005). We saw the mediation of language for reading for all three measures of reading (i.e., word attack, fluency, comprehension), thus supporting the notion that both word reading and reading comprehension are influenced by oral language. Additionally, the current findings provide important new support for the role of oral language in the reading development of CHH, and the means by which HL and aided hearing influence reading abilities among these children.

Writing—In addition to oral language mediating reading development, we also found that oral language mediates writing. Unlike the extensive literature on the reading-language relationship, there has been much less research concerned with spelling and writing. Researchers who have proposed advanced models of the underlying skills contributing to spelling and writing agree that there are several skill sets. Most accounts place oral language in a central place among these skills (Mehta et al. 2005; Hooper et al. 2010; McCutchen et al. 2014; O'Rourke et al. 2018). Therefore, it is not surprising that the index of moderated mediation of oral language on written language was similar to that of reading. It is quite likely that reading and written language (spelling and writing) are reciprocal (Caravolas et al. 2001; Shanahan et al. 2006).

Calculation—We also found that the mediated moderation model involving aided hearing and language extended to calculation skills. The role of oral language in calculation skills has not been extensively addressed in CNH and is not as obvious as that of reading and writing. Children with developmental language disorders are less skilled than their typically developing peers at calculation (Donlan et al. 2007; Fazio 1996). Koponen and colleagues (2007) have provided evidence that reading and calculation both draw on rapid lexical retrieval (verbal fluency) and this may serve as a common basis for poor oral language, reading, and calculation. The moderated mediation analysis in the current study is consistent with an association between oral language and computation; however, there have been few studies on verbal fluency among CHH. Fitzpatrick (2013) reported that the hearing aid users in their study were within normal limits on a verbal fluency task. The current data suggests that the age-appropriate levels of achievement in calculation may be reflective of the moderating effects of hearing aids.

Limitations of Current Study

Interventions other than aided hearing—We conclude that the generally good outcomes of the CHH are partly the result of early hearing aid provision. Early provision of amplification enables CHH to acquire oral language skills by early school entry that are sufficient to support the development of age-appropriate academic skills. These conclusions seem plausible given our earlier findings that early hearing aid fitting, greater daily use, and enhanced aided BESII are all associated with better growth of oral language (Tomblin, Harrison et al. 2015). In the current study, we only focused on aided BESII; it is likely that age of fitting and extent of daily use are also factors in the moderating effects of hearing aids. We acknowledge that early intervention often entails a number of other activities such as family-centered guidance to optimize parental language engagement, direct aural rehabilitation, center-based preschool services, and classroom-based hearing assistive devices. In this respect, our estimates of the magnitude of the moderation of unaided hearing on academic outcomes are likely to be very conservative. Additional research concerned with other dimensions of intervention also needs to be conducted.

Non-experimental design—We should emphasize that our conclusions of moderating effects of aided hearing imply a causal action of aided hearing on oral language. There is considerable debate regarding the kinds of evidence needed for causation. The strongest evidence is generally regarded as coming from experiments in which subjects are randomly assigned to controlled treatments. The current study was observational. In this regard, the statistical associations themselves are not conclusive evidence that aided hearing causes improved oral language, or that these effects on oral language cause improved academic outcomes. Recently, Bollen and Pearl (2013) argued with regard to data coming from statistical modeling that “Fitting the data does not ‘prove’ the causal assumptions, but it makes them tentatively more plausible. Any such positive results need to be replicated and to withstand the criticisms of researchers who suggest other models for the same data” (p. 309). We interpret the current data in this way, given that our findings are consistent with associations reflecting causal or instrumental actions. A more conservative interpretation also has important implications for consideration of the relationship between HL and academic outcomes. At a purely statistical level, interaction terms involving two predictor variables and an outcome mean that the relationship of one variable depends on the other. The significant interaction between unaided and aided hearing on oral language shows that research on communication and academic outcomes of CHH requires the inclusion of variables related to aided hearing. Studies that find no association between unaided hearing and outcomes that do not incorporate these potential intervening factors of aided hearing should refrain from assuming that the unaided hearing levels did not place children at risk.

Limited representation of lower socioeconomic status families—Most studies face the challenge of enrolling and retaining families from lower SES strata. This study also faced this challenge, despite our efforts to have a broad representation of SES. Low SES has often been shown to be associated with poorer oral language and educational outcomes (Bradley & Corwyn 2002). It is quite likely that the effects of HL could amplify, either additively or multiplicatively, the effects of SES on language and academic outcomes. Thus, we need to be cautious with regard to the degree to which children with mild and moderate losses from lower SES homes can be expected to have good outcomes.

Conclusions

This study clarifies the mixed results of past research on language and academic outcomes of children with mild to severe HL. Despite a clear risk for underachievement in academic outcomes, many children with HL show resilience by performing at a level comparable to a matched control group of hearing peers. This resilience was shown to be attributable, in part, to the benefits of aided hearing. Usually, the provision of hearing aids occurs in conjunction with other early intervention services focused on communication skill development. It is very possible that these factors also contributed to the resilience we found. We found that children with moderate HL appeared to show considerable resilience because their outcomes were often nominally better than children in the mild HL group and significantly better than children in the moderately-severe group. We suspect that children with moderate hearing loss may present an optimal match of hearing loss severity with the intervention services provided. In contrast with children with mild hearing loss, children with moderate hearing loss are likely to be fit early, wear their hearing aids regularly, and receive early communication intervention. Unlike the children with moderately-severe hearing loss, children with moderate hearing loss are also able to obtain high levels of aided audibility (SII). The fact that we observed good resilience among children with moderate hearing loss strongly suggests that further improvement in audibility for those with moderately-severe hearing loss should yield similar good outcomes.

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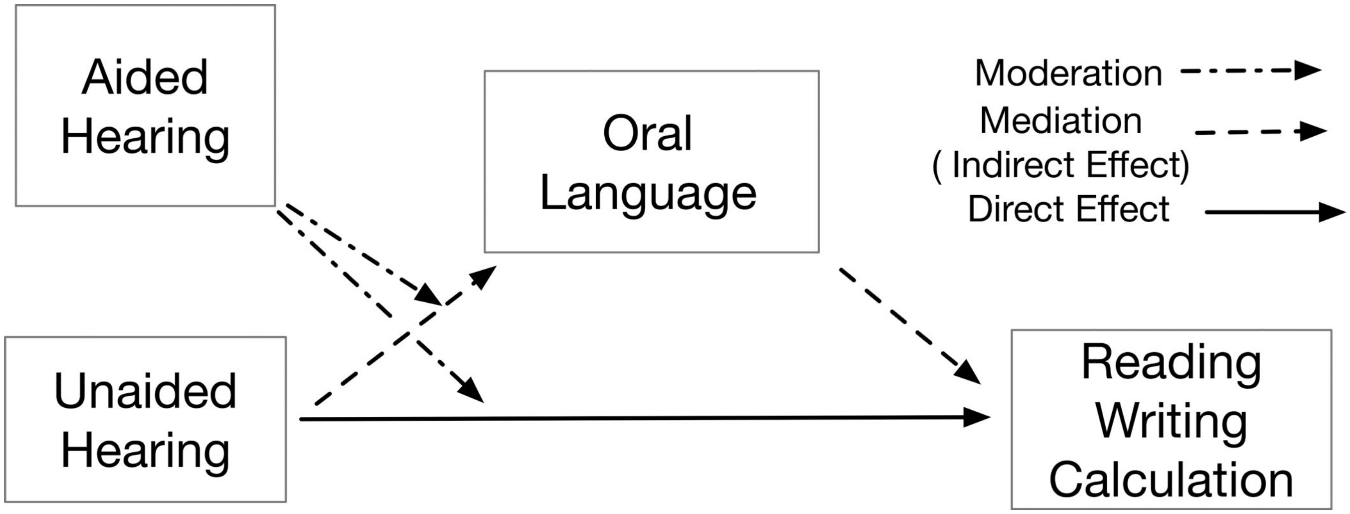

Figure 1.
A conceptual model depicting the moderation of the effect of unaided hearing (better-ear pure tone average) on academic outcomes by aided hearing (better-ear speech intelligibility index) through direct effects on academic outcomes or indirect (mediating) effects of oral language.

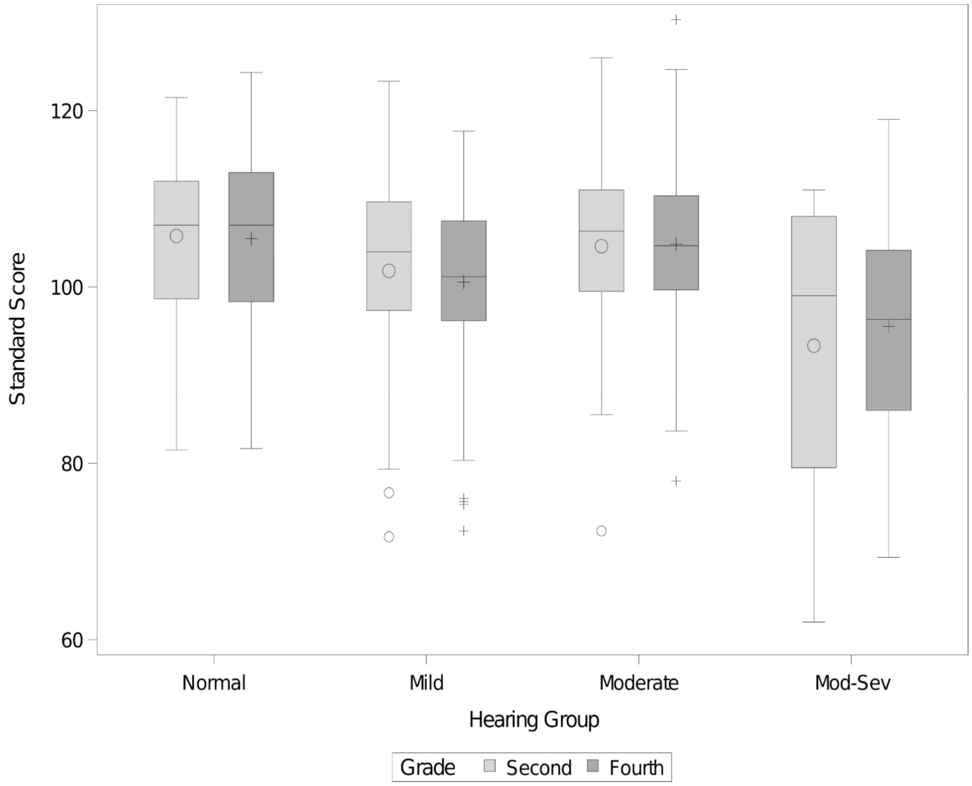

Figure 2.

Means and standard deviations of standard scores at second and fourth grade across hearing level group for oral language.

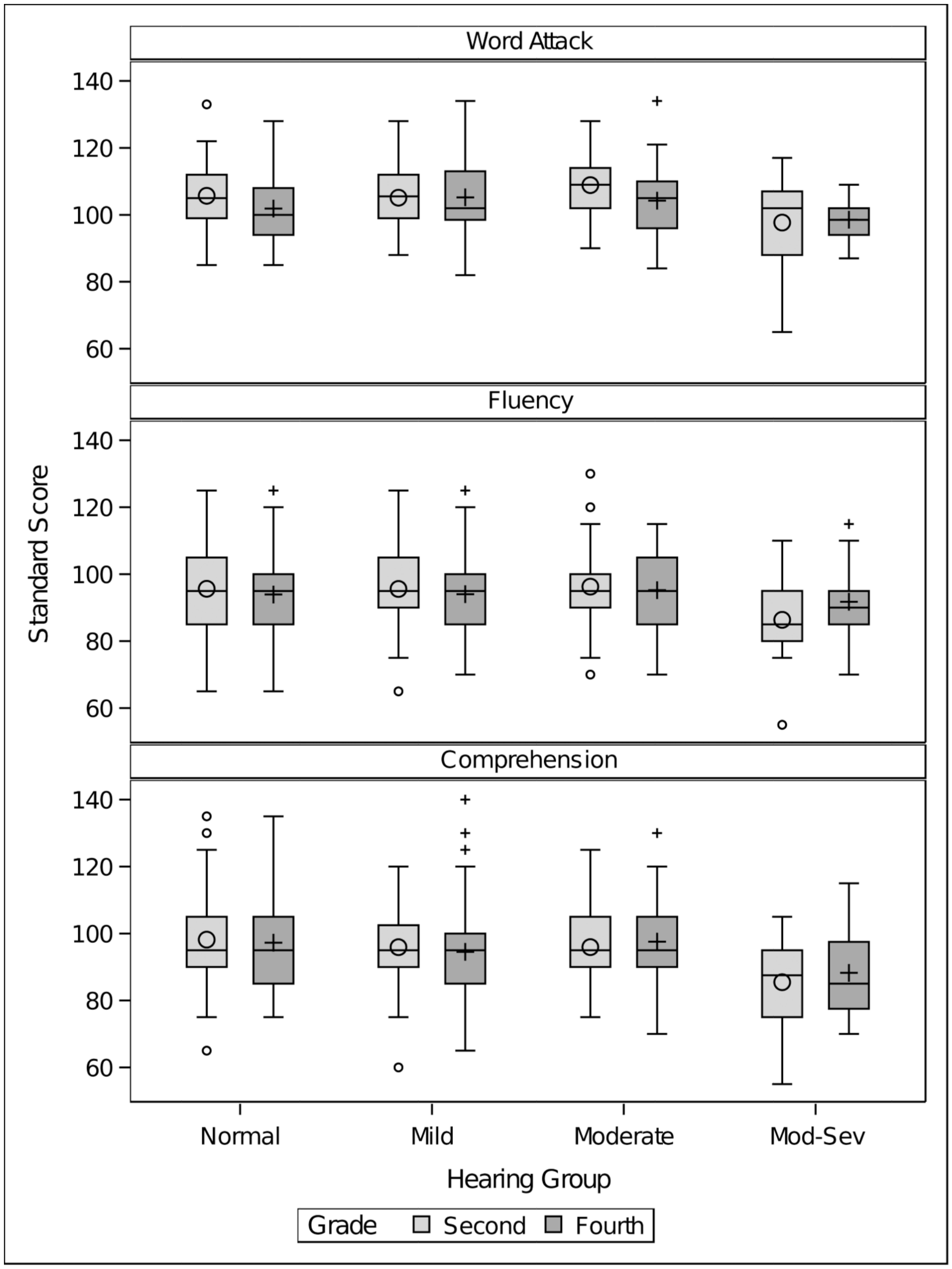

Figure 3.

Means and standard deviations of standard scores at second and fourth grade across hearing level groups for measures of reading nonwords (Word Attack), reading real words (Fluency), and reading comprehension.

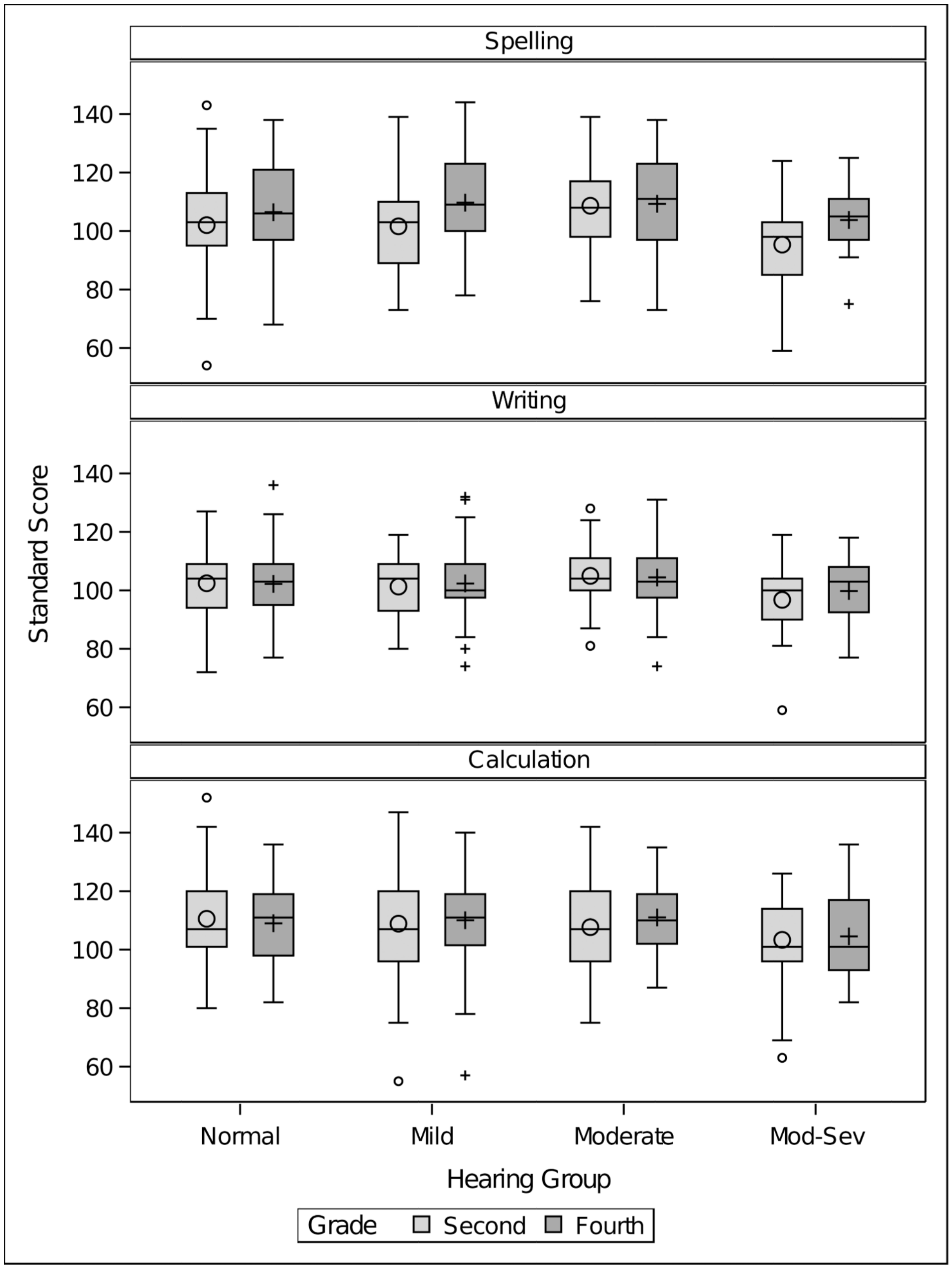

Figure 4.
Means and standard deviations of standard scores at second and fourth grade across hearing level groups for measures of spelling, writing, and calculation.

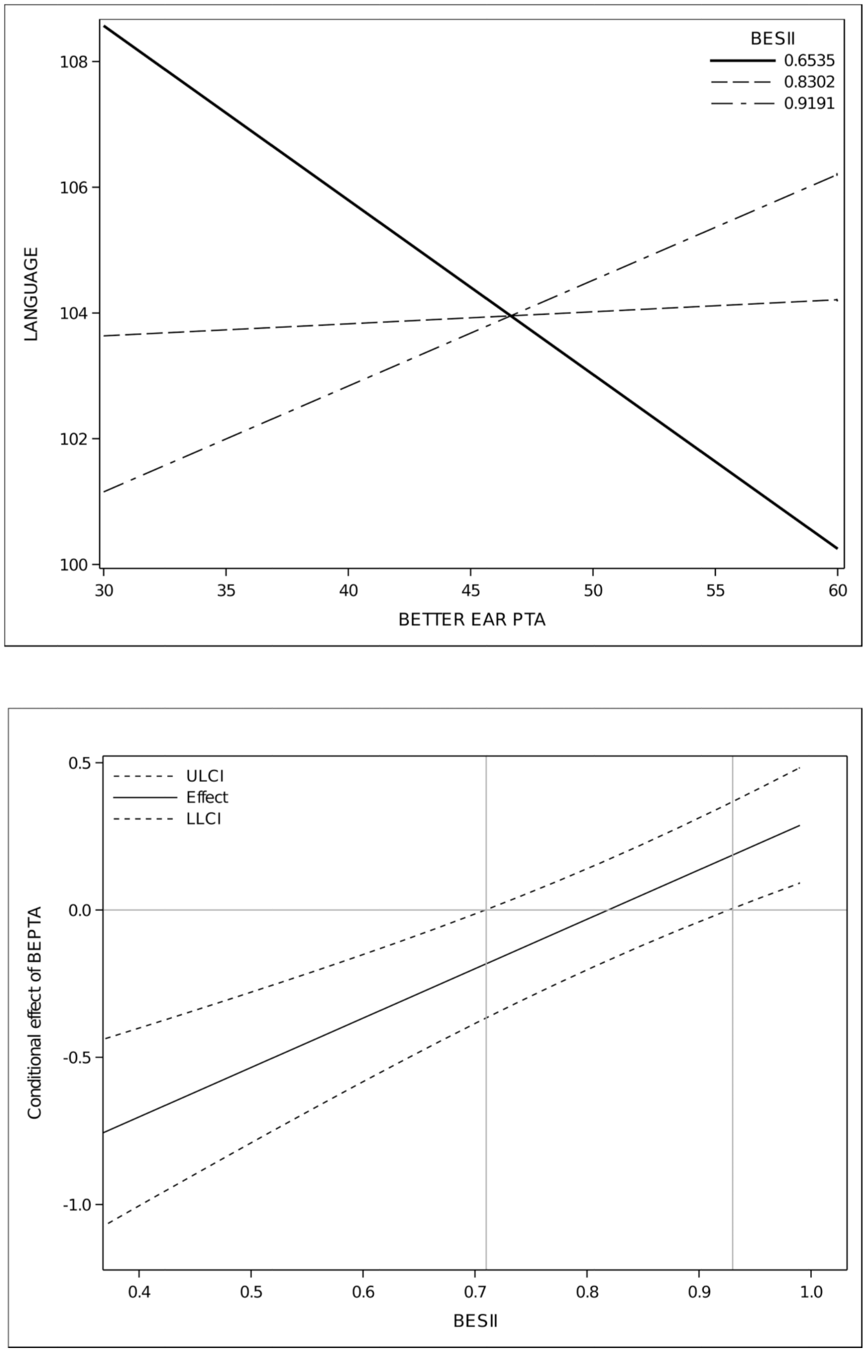

Figure 5.

The upper panel shows the linear relationship between better-ear pure tone average (BEPTA) and oral language ability at three values of aided better-ear speech intelligibility indices (BESII) representing the 16th, 50th, and 84th percentiles of aided BESII. The slopes shown represent the predicted effect of BEPTA conditioned on aided BESII. The lower panel plots these conditional slope values across levels of aided BESII values and the 95% confidence intervals. The vertical lines at 0.71 aided BESII and 0.93 aided BESII identify regions where the predicted effect falls below the 95% confidence interval, is within these intervals or is greater than 0. ULCI = upper-level confidence interval, LLCI = lower level confidence interval.

Table 1.

Distribution of mother's education by hearing level and child's grade at testing.

Hearing Level	Grade	Mother's Education				Mean (SD) Wilcoxon Score
		1	2	3	4	
Normal	2	19	9	27	24	116.610 (452.31)
	4	15	10	23	21	100.64 (369.84)
Mild	2	12	19	18	16	107.64 (429.37)
	4	13	16	18	17	94.15 (363.05)
Moderate	2	10	17	15	17	112.28 (416.63)
	4	9	10	14	12	95.92 (325.02)
Moderate to Severe	2	3	4	9	7	124.22 (286.11)
	4	1	2	10	7	120.73 (233.89)

Mother's educational levels: 1=high school, 2=post-secondary attendance, 3=college graduate, 4= post-graduate levels of education.

Table 2.

Means and (standard deviations) for scores from language and academic outcomes measures for children with normal hearing, mild, moderate, and moderate to severe hearing loss.

Hearing Grade Status			Outcome						
			Calculation	**Reading Comprehension**	**Reading Fluency**	**Oral Language**	**Spelling**	**Word Attack**	**Writing**
Normal	2	110.56 (14.92)	98.16 (12.76)	95.63 (12.26)	105.80 (9.45)	98.16 (12.76)	105.70 (8.72)	102.42 (11.68)	
	4	109.03 (13.13)	97.25 (13.19)	93.91 (12.09)	105.48 (10.64)	97.25 (13.19)	101.87 (9.74)	102.17 (12.24)	
Mild	2	108.89 (18.21)	95.92 (11.33)	95.58 (11.72)	101.84 (11.04)	95.92 (11.33)	105.13 (9.38)	101.29 (11.04)	
	4	110.06 (15.79)	94.52 (13.84)	94.03 (12.93)	100.57 (10.62)	94.52 (13.84)	105.22 (11.43)	102.36 (11.76)	
Moderate	2	107.69 (14.90)	95.93 (11.69)	96.27 (12.37)	104.63 (9.29)	95.93 (11.69)	108.88 (8.68)	104.95 (9.47)	
	4	111.02 (12.46)	97.56 (13.64)	95.22 (12.15)	104.87 (10.84)	97.56 (13.64)	104.24 (10.57)	104.41 (12.63)	
Moderate to Severe	2	103.35 (15.67)	85.45 (12.72)	86.36 (12.83)	93.35 (16.95)	85.45 (12.72)	97.70 (12.19)	96.74 (12.19)	
	4	104.55 (15.73)	88.25 (12.90)	91.75 (10.67)	95.55 (12.89)	88.25 (12.90)	98.55 (5.89)	99.75 (12.15)	

Table 3.

Summary statistics for general linear mixed models testing effects of better-ear pure tone average and grade at testing on language and academic outcomes.

Outcome	**Effect**	**Numerator *df***	**Denominator *df***	***F***	***p***
Oral language					
	PTA	3	269	10.30	.00
	Grade	1	146	0.05	.82
	PTA*Grade	3	146	0.92	.43
WJ III Word Attack					
	PTA	3	269	7.03	.00
	Grade	1	146	26.97	.00
	PTA*Grade	3	146	2.04	.11
GORT-5 Fluency					
	PTA	3	263	2.99	.03
	Grade	1	144	2.83	.09
	PTA*Grade	3	144	3.81	.01
GORT-5 Comprehension					
	PTA	3	264	6.35	.00
	Grade	1	144	0.03	.86
	PTA*Grade	3	144	1.04	.38
WJ III Spelling					
	PTA	3	269	3.37	.02
	Grade	1	146	25.71	.00
	PTA*Grade	3	146	2.22	.09
WJ III Writing Samples					
	PTA	3	269	3.37	.02
	Grade	1	145	0.70	.40
	PTA*Grade	3	145	0.37	.77
WJ III Calculation					
	PTA	3	268	1.14	.33
	Grade	1	146	0.38	.54
	PTA*Grade	3	146	1.41	.24

Note. PTA = pure tone average; WJ III = Woodcock-Johnson III Tests of Achievement; GORT-5 = Grey Oral Reading Tests – Fifth Edition.

Table 4.

Moderation of effects of BEPTA on oral language by aided SII and mediation of written language by oral language

	Coefficient	***SE***	***p***
Moderation of Oral Language (R^2= 0.24)			
Intercept	161.49	17.76	.0000
BEPTA	−1.37	0.26	.0000
Aided SII	−78.25	19.25	.0001
BEPTA*Aided SII	1.68	0.30	.0000
Mother's education	2.50	0.71	.0005
Mediation by Oral Language on Reading(R^2= 0.58)			
Intercept	33.38	5.19	.0000
BEPTA	−0.08	0.04	.02
Oral language moderated by aided SII	0.66	0.05	.0000
Mother's education	0.55	0.50	.27
Mediation of Oral Language on Writing (R^2 = 0.56)			
Intercept	35.21	5.28	.0000
BEPTA	−0.06	0.04	.13
Oral language moderated by aided SII	0.66	0.05	.0000
Mother's education	0.41	0.51	.42
Mediation of Oral Language on Calculation (R^2= 0.19)			
Intercept	51.08	9.91	.000
BEPTA	0.009	0.06	.90
Oral language moderated by aided SII	0.54	0.09	.0000
Mother's education	0.80	0.96	.41

Note. BEPTA = better-ear pure tone average; SII = speech intelligiblity index.