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# Effects of Frequency of Early Intervention on Spoken Language and Literacy Levels of Children Who are Deaf or Hard of Hearing in Preschool and Elementary School

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**Abstract:** Language delays associated with hearing loss during infancy may have a negative impact on academic development throughout childhood. Early intervention provided by the Moog Center for Deaf Education prior to 36 months of age was quantified, and associations with later outcomes were examined for 50 students who are DHH representing Moog Center alumni. The objective was to determine whether the amount of early intervention (referred to hereafter as dose of early intervention received at the Moog Center during the time children were 0–36 months of age) contributed uniquely to outcomes in preschool (4–6 years) and in elementary school (8–14 years). Analysis of language and reading outcomes concluded that greater doses of early intervention were beneficial, even when other contributing factors such as degree of hearing loss, nonverbal intelligence, and age at first intervention were taken into account. Those children with poor aided speech perception scores in preschool exhibited the most benefit from early intensive intervention. Average language scores were within the expected range in comparison with hearing peers in preschool and remained within expectation when assessed an average of four years later in elementary school. The intensity of early intervention provided at the Moog Center contributed significantly to long-term development of language and literacy over and above the benefits associated with the age at which intervention was delivered.

**Key Words:** early intervention, language and literacy in deaf and hard of hearing children, listening and spoken language intervention

**Acronyms:** BKB-SIN = Bamford-Kowal-Bench Speech in Noise; CASL = Comprehensive Assessment of Spoken Language; CELF-P = Clinical Evaluation of Language Function-Preschool; CI = cochlear implant; DHH = deaf or hard of hearing; EI = early intervention; HA = hearing aid; HL = hearing loss; LNT = Lexical Neighborhood Test; LSL = listening and spoken language; mLNT = Multi-syllabic Lexical Neighborhood Test; NVIQ = Nonverbal Intelligence; PPVT = Peabody Picture Vocabulary Test; PTA = pure tone average; SLP = speech-language pathologist; SNR = signal to noise ratio; TORC = Test of Reading Comprehension; UNHS = Universal Newborn Hearing Screening; VIQ = Verbal Reasoning; WISC-V = Wechsler Intelligence Scale for Children; WNL = within normal limits; WRMT = Woodcock Reading Mastery Test

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The adoption of universal newborn hearing screening (UNHS) in the majority of states in the United States has enabled earlier identification of children with congenital hearing loss. The goal of screening by one month, confirmation by three months, and intervention by six months is intended to maximize linguistic and communicative competence, including providing infants with the opportunity for amplification as early as possible (JCIH, 2000). As a result, programs for children who are deaf or hard of hearing (DHH) have focused on early identification and intervention during the birth to three age range (Yoshinaga-Itano, Sedey, Coulter, & Mehl, 1998). Evidence suggests that children who are DHH and are enrolled at younger ages in early intervention (EI) demonstrate better language skills by the end of preschool than do later-enrolled children, regardless of degree of hearing loss (Moeller, 2000). This EI period is particularly critical to Listening and Spoken Language (LSL) service providers, where the focus is on comprehension and intelligible production of speech (Estabrooks, 2006). The achievement of spoken language skills commensurate with those of hearing age-mates during the preschool years is a primary objective of such EI programs (Moog, 2002). Although research suggests intervention should begin as early as possible, little evidence is available concerning the optimal amount or intensity of EI for reaching this objective for children who are DHH.

Research that is specifically designed to assess the effects of increasing the intensity (dose) of intervention in children with communication disorders has reached mixed conclusions. A greater number of hours of intervention has resulted in improved phoneme production in three to six-year-olds with speech disorders (Cummings, Hallgrimson, & Robinson, 2019) and better spoken vocabulary in children with Down Syndrome (Yoder, Woynaroski, Fey, & Warren, 2014). A meta-analysis of treatment studies of children with developmental speech and language delays found greater expressive language gains for interventions that were longer in duration (Law, Garrett, & Nye, 2004). However, a report by Fey, Yoder, Warren, & Bredin-Oja (2013) of children with delayed vocabulary acquisition and no diagnosis of autism at 18–27 months showed that greater intervention was not necessarily associated with better outcomes. Similar results were reported in a study of five to eight-year-olds diagnosed with language impairment (Schmitt, Justice, & Logan, 2017).

A few studies have addressed the effects of intervention dose on spoken language acquisition in children who are DHH. One nationwide study tested 112 five-and six-year-olds who had used a CI for at least one year and received early LSL intervention (Moog & Geers, 2010). The analysis examined the effects of age and type of intervention on preschool outcomes across a broad battery of standardized spoken language measures including vocabulary, verbal reasoning, and global language skills. Educational interventions included individual parent-child coaching in LSL strategies and preschool classes. These programs differed in their intensity, with classes occurring several times each week for at least two hours, while individual parent-child sessions generally consisted of weekly one-hour sessions. Depending on the specific outcome assessed, between 44% and 65% of the sample scored within normal limits (WNL)—defined as within one standard deviation of hearing age-mates—by the end of preschool. The probability of achieving scores WNL was increased for children who received a CI by 24 months of age. In addition, placement in an LSL-specialized class by two years of age further increased the probability of age-appropriate language scores. More importantly, 71% of those who attended an LSL class from two through four years of age scored WNL compared to only 41% of those who did not start preschool until age three (averaged across tests).

A more recent study examined the effects of specialized preschool education on language and literacy skills in DHH children between three and five years of age by comparing progress during the school year with progress over summer months without formal intervention (Scott, Goldberg, Connor, & Lederberg, 2019). Vocabulary, phonological awareness, and letter-word identification skills all improved during the school year, but not during the summer. This result highlights the importance of preschool for DHH children and argues in favor of increasing the intensity of preschool intervention. Chu and colleagues (2016), on the other hand, reported that greater frequency and dose of individual EI sessions were not related to better receptive communication outcomes in children given a cochlear implant by age 7, even though children with higher doses of EI services tended to be in families who had greater relative socio-economic advantage. Children with earlier access to cochlear implants demonstrated better expressive language with less total EI dose than was documented for children who received a CI later.

The advent of cochlear implantation has brought the goal of normal spoken language within reach for many more children by increasing their early auditory access to speech. Even after appropriate sensory devices are provided, language delays associated with hearing loss during this early formative period may continue to have a negative impact on academic development through elementary grades and high school (Geers, Nicholas, Tobey, & Davidson, 2016; Geers, Strube, Tobey, Pisoni, & Moog, 2011; Moog & Geers, 2010). It is, therefore, important to document the type and dose of EI needed to optimize the chances of achieving age-appropriate spoken language.

The current study examined the outcomes of a specific LSL EI program for children who are DHH, the Moog Center for Deaf Education. The intensity of intervention provided by the Moog Center prior to 36 months of age was quantified, and associations between amount of Moog Center EI and later outcomes in children who are DHH were examined. Outcomes were measured for 50 children at two points in time: the first testing occurred at the end of Moog Center preschool and the second testing occurred, on average, four years later during general education elementary school (here, defined as grades two through eight). The goals of this investigation were as follows:

- To document speech perception, spoken language, cognitive, and reading outcomes in a sample recruited from all eligible alumni of the Moog Center for Deaf Education.
- To quantify the dose of intervention (as measured in number of hours) each child accumulated in the Moog Center EI program between birth and 36 months of age.
- To determine whether dose of EI received at the Moog Center contributed uniquely to language and literacy outcomes in preschool and, later, in elementary school.

## Method

Families of all children with a better ear unaided pure tone average (PTA) threshold of 40dB hearing loss (HL) or greater who had attended the Moog Center by 6.5 years of age and were currently between 8.0 and 14.0 years old (*N* = 60) were contacted for follow-up testing. Each child, accompanied by a parent, was invited to attend a one-day testing session, held at the Moog Center, with all travel expenses paid for families living outside of the local (St. Louis) area. The test battery was completed successfully by all but one child, for whom testing was discontinued because the child became ill. Preschool speech perception and language scores were obtained from the Moog Center's files for each of these children from when they were between three and six years old. All testing was conducted at the Moog Center by qualified audiologists, speech-language pathologists (SLPs), psychologists, and LSL teachers. Parents and children individually consented to participate in data collection, analysis, and reporting. Human Subjects Review for this study was conducted and approved by IntegReview IRB, Austin, TX.

### Participants

Fifty of the 60 alumni who qualified (84% of the total qualifying population), returned for a testing session. Table 1 compares mean characteristics of the tested sample with those of the ten qualifying children who did not attend a follow-up session. ANOVAs comparing mean characteristics of the two samples revealed only one statistically significant difference; children who did not return for follow-up assessment had higher average nonverbal intelligence scores than those who did return. Thus, it appears that the tested sample was representative of children attending this program in most characteristics and was not biased toward better-performing subjects.

**Table 1**
***Student Demographics***

| | *Mean* | *Standard Deviation* | *Range* |
|---|---|---|---|
| Age at Identification (mos)—Test group (*N* = 50) | 11.9 | 13.3 | 0.5–51 |
| Non-participant group (*n* = 10) | 15.2 | 16.1 | 0.5–42 |
| | | | |
| Age at First Hearing Aid (mos)—Test group | 16.1 | 14.3 | 0.75–57 |
| Non-participant group | 16.7 | 15.5 | 1–46 |
| | | | |
| Better Ear Unaided PTA[1] (dB HL)—Test group | 89.9 | 28.5 | 43.3–120.0 |
| Non-participant group | 86.8 | 25.0 | 46.7–113.3 |
| | | | |
| Preschool mLNTe[2] (% correct)—Test group | 77.7 | 23.3 | 8.3–100 |
| Non-participant group | 76.7 | 23.2 | 16.7–100 |
| | | | |
| Preschool Celf-P3[3] (St. Score)—Test group | 91.2 | 19.4 | 50–125 |
| Non-participant group | 84.7 | 20.0 | 57–112 |
| | | | |
| *NVIQ[4] —Test group | 101.3 | 14.1 | 74–132 |
| Non-participant group | 111.6 | 6.9 | 100–127 |
| | | | |
| Maternal Education (yrs)—Test group | 15.6 | 2.3 | 10–20 |
| Non-participant group | 14.8 | 1.9 | 112–18 |
| Gender (percent)—Test group | 44% Female | | 56% Male |
| Non-participant group | 40% Female | | 60% Male |

[1]PTA – Pure Tone Average (500, 1000, 2000 Hz) in dB, hearing level, better ear unaided
[2]mLNTe – Multisyllabic Lexical Neighborhood speech perception Test - easy list percent correct
[3]CELF-P3 – Clinical Evaluation of Language Function – Preschool Level, Standard Score
[4]NVIQ – Nonverbal Intelligence Quotient – Wechsler Intelligence Scale for Children, 5th edition (WISC-V)
*The non-participant group that did not come back for testing had significantly higher Non-Verbal IQ scores.

All but four of the children had documented congenital or pre-lingual (i.e., before 36 months) onset of HL, as well as early identification and early intervention. Although age at onset of HL could not be confirmed for these four children, identification of HL occurred at 24, 44, 49, and 53 months of age, and hearing aids were fit between 50 and 54 months of age.

Table 2 summarizes the intervention and assessment history for the 50 participants in this study. Children ranged from 1 month to 6.5 years old when they entered the Moog Center and were between 4 and 10 years old when they graduated. Children graduated at an average age of 6.4 years, having spent an average of 4.2 years at the Moog Center. Upon graduation, 48 of the children entered general education classes with hearing children and two students were homeschooled. Most of the children received additional support in the general education setting, including services from itinerant teachers of the deaf, SLPs, special educators, and remote microphone technology.

delivery are provided, depending on the child's age. For children younger than 18 months, the program is primarily parent-centered, and for children 18 to 36 months, a child-focused component is also provided. All EI providers are either LSL teachers of the deaf or SLPs. The Moog Center's intervention setting also includes audiologists, so if any problems occur on-site with a child's hearing aid or cochlear implant, a qualified professional will trouble-shoot immediately. If the problem cannot be fixed, the child is fitted with a loaner device. Back-up hearing aids and cochlear implants from the three companies that market CIs in the United States are on-hand for loan when needed. The audiologists recognize the importance of access to sound and are available on weekends and holidays to ensure uninterrupted access to sound. In addition, parents are trained on troubleshooting their child's sensory aid.

The program for children under 18 months consists of one-hour home visits by an EI provider at least twice a month and a Center visit once a month. Home visits include providing parents information about hearing loss and its impact on a child's acquisition of spoken language, importance of amplification, discussion of parents' concerns, activities and strategies to help parents facilitate their child's learning to talk, and other information and topics of interest. All visits also include at least a 20-minute period of an EI provider coaching the parent engaged in an activity with his or her child. The monthly Center visit includes an individual parent-child session and an appointment with one of the Center's pediatric audiologists. Only the parent-child portion of the Center visit was included in the calculation of hours.

**Table 2**
***Intervention and Assessment History***

| | *Mean* | *Standard Deviation* | *Range* |
|---|---|---|---|
| Age at Identification (mos) | 12.1 | 13.4 | 0.5–51 |
| Age at First Intervention (mos) | 18.5 | 15.6 | 1–58 |
| Age Enrolled Moog Center (mos) | 26.3 | 20.5 | 1–78 |
| Age Graduated Moog Center (yrs) | 6.4 | 1.6 | 3.7–10.0 |
| Duration of Moog Center Intervention (yrs) | 4.2 | 1.8 | 1.2–8.1 |
| Age at Preschool Assessment (yrs) | 4.5 | 0.7 | 3.1–6.5 |
| Age at Elementary Assessment (yrs) | 10.5 | 1.9 | 8.1–14.0 |
| Duration from Graduation to Elementary Assessment (yrs) | 4.0 | 2.0 | 0.9–7.8 |

At the time of preschool testing, 16 of the children used hearing aids (HA), and 34 were cochlear implant (CI) users; 14 children received at least one CI before 18 months of age, and 21 received a CI after 18 months of age. All but one of the children received his or her first CI before age five. All but two of the families reported their child used a sensory aid at least 8 hours daily during the preschool years.

At time of follow-up testing, 35 children used at least one CI (6 bimodal, 28 bilateral, and 1 unilateral). Fifteen children continued using two hearing aids. As expected, PTA threshold average differed significantly among device users (*mean* = 115dB HL for CI-only users, 75dB HL for bimodal users, and 50 dB HL for HA-only users). Almost all (*n* = 49) parents reported sensory aid use during all waking hours, and one reported use 5 days a week during school.

**Intervention**

The Moog Center EI program serves children from birth to three years of age and their families. Two types of service

Children 18 months and older attend a center-based toddler class, which is offered every day from 8:30 to noon. Children attend two, three, four, or five mornings a week depending on their age, maturity, and family factors such as distance from the Moog Center, jobs, other commitments, and so forth. For children, participation in the toddler class includes three components: (a) one-hour of individual therapy intervention for the child, (b) two and half hours of group experiences for the child, and (c) weekly 30-minute individual sessions for the parent with his or her child. Individual therapy intervention for the child focuses on the development of spoken language skills including explicit teaching of vocabulary, language, speech, and listening skills. For the group sessions, children are organized in classes of six children, where they engage in circle time, gross motor activities, centers, a variety of fine motor and cognitive activities, and snack time. The weekly 30-minute individual parent-child session includes the EI provider coaching the parent engaging with his or her child and discussion about the child's language development (Brooks, 2016).

To assess the intensity of the program for each child, our goal was to specify dose (number of hours) of participation in the Moog Center EI program. To quantify the dose of intervention, we examined billing and attendance records for each of the 50 Moog Center alumni who returned for testing. The total number of hours attended at the Moog Center prior to 36 months was determined, with individual intervention sessions encompassing home visits, Center visits, individual child therapy, and individual parent-child sessions. Calculations for group intervention included hours spent in the toddler class between 18 and 36 months of age.

The dose distribution is summarized in Figure 1 for each of the 50 children. The histogram depicts the total number of hours each child had attended the Moog Center between 0–36 months of age by frequency-ordered columns. The first 15 subjects depicted without a frequency column in Figure 1 did not begin attending the Moog Center until after their third birthday and thus showed zero hours of intervention. Ten of these 15 children were enrolled in EI elsewhere before attending the Moog Center. For children who received intervention elsewhere before enrolling in the Moog Center, age at first HA represents age at first intervention. The remaining 35 children in the sample attended both individual and group sessions at the Moog Center. Hours of individual intervention for all 50 children ranged from zero to 279 and group intervention for all children ranged from zero to 482.

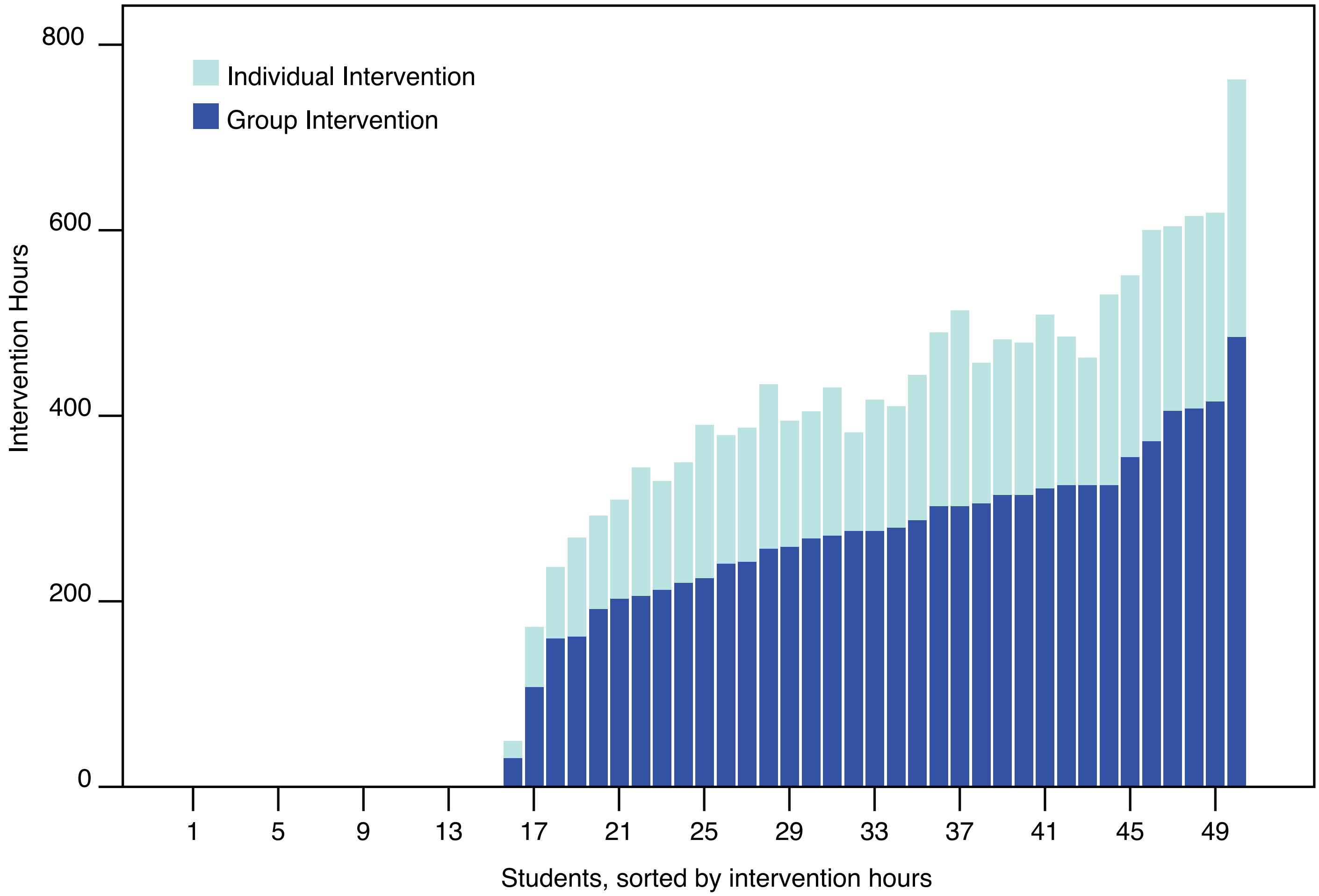


***Figure 1.* Number of hours of group of intervention at the Moog Center betweeen 0 and 36 months of age.** Hours of intervention are plotted in stacked bars for each of 35 Moog Center alumni. Fifteen subjects did not have any Moog Center intervention in that time frame.

**Preschool Assessment**

**Speech perception.** *Multi-syllabic Lexical Neighborhood Test* (mLNT; Kirk, Pisoni, & Osberger, 1995) was designed to measure auditory word recognition in very young children who are DHH. This open-set test consists of 24 multi-syllable words representative of the vocabulary of young children (e.g., *purple, glasses, again, animal*). Two sub-lists within each set contain 12 "easy" words that frequently occur in the English language and are less likely to be confused with other words and 12 "hard" words that occur less frequently and can be easily confused with similar sounding words. Scores were consistently available for all children on the easy list, so only scores on that 12-word list are represented in this report. The target words were presented at 60 dB SPL in quiet, and the children responded by repeating the word they heard. The word was scored as correct if the response was recognizable as the target word.

**Spoken language.** *Clinical Evaluation of Language Function-Preschool* (CELF-P; Wiig, Secord, & Semel, 2004) is a comprehensive language assessment normed on hearing children between 3.0 to 6.9 years of age. The particular subtests administered varied slightly based on age at test (Basic Concepts, Sentence Structure, Concepts & Following Directions, Word Structure, Expressive Vocabulary, and Recalling Sentences). Subtest scores were combined into a Total Language standard score using age-appropriate norms for hearing children with an average range from 85 to 115.

**Receptive vocabulary.** *Peabody Picture Vocabulary Test* (PPVT; Dunn & Dunn, 2007) is a receptive vocabulary test standardized on hearing subjects between infancy and adulthood. The examiner provides a spoken label, and the student selects one of four pictures that best represents the label. Testing is discontinued after the student misses 8 out of 12 in a set. Results were expressed as a standard score in relation to hearing age-mates in the normative sample with an average range from 85 to 115.

**Elementary School Assessment**

**Speech perception.** *Lexical Neighborhood Test* (LNT; Kirk et al., 1995) measures open-set auditory word recognition in children who are DHH. This open-set test consists of 50 single-syllable words representative of the vocabulary of young children (e.g., *pink, more, hit, juice*). The list contains 25 easy words and 25 hard words as described above for the mLNT. The target words were presented at 60 dB SPL in quiet, and the children responded by repeating the word they heard.

*BKB-SIN Speech-in-Noise Test* (Etymotic Research, 2005; Bench & Bamford, 1979; Bench, Kowal, & Bamford, 1979) measures a child's ability to understand speech in background noise. This open-set test consists of lists of sentences, each of which contains three or four keywords. Sixteen or twenty of the sentences were presented in a background of four-talker babble noise (Auditec, 1971) based on whether the child used cochlear implants or hearing aids. The level of noise increased with each sentence, reflecting easy to difficult listening situations. The target sentences were presented at 65 dB SPL in increasingly difficult signal to noise ratios, and the children responded by repeating each sentence. Based on the number of keywords repeated correctly, a signal to noise ratio (SNR)-50 score is calculated. The SNR-50 score indicates how much louder sentences must be above the noise for a child to understand approximately 50% of spoken words.

**Spoken language.** *Comprehensive Assessment of Spoken Language* (CASL; Carrow-Woodfolk, 1999) measures spoken language in hearing children between three and 21 years of age across four structural categories: Lexical/Semantic, Syntactic, Supralinguistic, and Pragmatic Language. All children received the core language subtests appropriate for their age: Antonyms, Synonyms, Paragraph Comprehension, Morphemes, Non-literal Language, and Pragmatics. Subtest scores were combined as described in the test manual and results are expressed as standard scores in relation to their hearing age-mates in the normative sample with an average range from 85 to 115.

**Vocabulary.** *Peabody Picture Vocabulary Test*, 4th edition (PPVT-4; Dunn & Dunn, 2007), described above from the preschool battery, was re-administered at the elementary school assessment.

**Reading.** *Woodcock Reading Mastery Test*, Revised, 3rd edition (WRMT; Woodcock, 2011) is an individual assessment of reading skills for children and adults. Subtests include Word Identification, Word Attack, Word Comprehension, and Passage Comprehension. Results were expressed as a standard score in relation to hearing age-mates in the normative sample with an average range from 85 to 115.

The *Test of Reading Comprehension, 4th edition* (TORC-4; Brown, Hammill, & Wiederholt, 2009) assesses silent reading comprehension using five subtests (Relational Vocabulary, Sentence Completion, Paragraph Construction, Text Comprehension, and Contextual Fluency). Results are expressed as a standard score in relation to hearing age-mates in the normative sample with an average range from 85 to 115.

**Cognition.** The *Wechsler Intelligence Scale for Children, 5th edition* (WISC-V; Weschler, 2014) is an individually administered intelligence test for children between the ages of six and 16 years. The index scores represent a child's ability in discrete cognitive domains. Non-verbal intelligence (NVIQ) included the following subtests: Block Design and Visual Puzzles (visual spatial skills), Matrix Reasoning and Figure Weight (fluid reasoning skills), Digit Span and Picture Span (working memory), Coding, and Symbol Search (processing speed). Verbal reasoning

(VIQ) included the subtests of Similarities and Vocabulary. Results are expressed as a standard score in relation to hearing age-mates in the normative sample with an average range from 85 to 115.

## Objectives

This study addresses both short-term and long-term effectiveness of Moog Center intervention provided to children up to 36 months of age. Short-term outcomes were assessed during preschool (3 to 6 years of age) and long-term outcomes during elementary school grades (8–14 years). Analyses addressed the four following questions.

Question 1: What levels of speech perception, vocabulary, and language are achieved at or near the end of Moog Center EI and preschool intervention?

Question 2: Does intensity of Moog Center intervention between 0–36 months predict children's language achievement in preschool?

Question 3: What levels of speech perception, vocabulary, language, verbal reasoning, and reading are achieved by Moog Center graduates at or near the end of elementary school?

Question 4: Does intensity of Moog Center intervention between 0–36 months predict children's language and reading achievement in elementary school?

## Results

**Question 1: What levels of speech perception, vocabulary and language are achieved at or near the end of Moog Center EI and preschool intervention?**
Table 3 summarizes test results gathered when children had completed preschool at the Moog Center or at the point of departure. Out of the 50 children, 25 (50%) scored within one standard deviation of their hearing age-mates (standard score > 85) on the overall language measure (CELF-P) and 82% achieved vocabulary scores on the PPVT within the average range. No statistically significant difference between language standard scores of the 15 children who used hearing aids and those 35 children who used at least one cochlear implant was found. Both device groups achieved average scores within expectation for hearing age-mates (HA = 101 and 92; CI = 95 and 86 for PPVT and CELF-P, respectively) by the time they either reached the end of preschool or exited from the Moog Center program. Aided speech perception scores on the mLNT averaged 78% and did not differ for CI and HA users, although there was large variability in performance. Despite very large differences in unaided PTA thresholds, CI users with severe-profound hearing losses did not differ from HA users with moderate impairment in their ability to understand speech through their devices.

**Question 2: Does intensity of Moog Center intervention between 0–36 months predict children's language achievement in preschool?**
The number of intervention hours correlated $r = .348$ ($p = .013$) with speech perception scores on the mLNT, $r = .645$ ($p < .001$) with global language skills measured by the CELF-P, and $r = .537$ ($p < .001$), with receptive vocabulary

**Table 3**
***Preschool Results for Vocabulary, Language, and Speech Perception***

| | *Mean* | *Standard Deviation* | *Range* | *Within Normal Limits (WNL)* |
|---|---|---|---|---|
| Age at Test (years) | 4.38 | 0.66 | 3.05–6.12 | - |
| Total PPVT[1] | 96.7 | 17.2 | 46–128 | 82% |
| *HA users (n = 15)* | *101.53* | *20.27* | *46–128* | 87% |
| *CI users (n = 35)* | *94.63* | *15.63* | *54–117* | *80%* |
| Preschool CELF-P2[2] | *87.8* | *18.7* | *50–125* | *50%* |
| *HA users (n = 15)* | *91.67* | *17.63* | *61–119* | *60%* |
| *CI users (n = 35)* | *86.20* | *19.20* | *50–125* | *46%* |
| mLNT easy[3] | *77.7* | *23.3* | *8–100* | n/a |
| *HA users (n = 15)* | *78.3* | *22.7* | *8–100* | n/a |
| *CI users (n = 35)* | *77.4* | *23.9* | *8–100* | n/a |

*Note.* HA = Hearing Aid; CI = Cochlear Implant; PPVT = Peabody Picture Vocabulary Test–standard score; CELF-P2 = Clinical Evaluation of Language Function, Preschool Level–standard score; mLNT = Multisyllabic Lexical Neighborhood Test (easy List)–percent correct.

measured by the PPVT. These positive correlations indicate children with more hours of Moog Center intervention between 0 and 36 months of age achieved higher speech perception, language, and vocabulary scores in preschool.

In terms of demographics, correlations between intervention hours over the 0–36 months of age and PTA threshold ($r$ = -.10), Mother's Education ($r$ = -.08), and WISC Nonverbal Intelligence ($r$ =.23) did not reach statistical significance; however, the correlation with age at first HA was statistically significant ($r$ = - .584; $p <$ .000). Children who received a HA (and typically began intervention) at younger ages accumulated more hours of Moog Center intervention between 0 and 36 months of age. Thus, it is important to separate the effects of these variables on outcome measures to determine the extent to which age at intervention and amount of early Moog Center intervention independently influence language outcome.

Multiple regression analysis assessed the contribution of intervention hours to preschool CELF scores after accounting for the independent contributions of demographic and child performance characteristics. Table 4 summarizes statistical significance levels for each variable independently. Collectively, the control variables (PTA threshold, age at first HA, mother's education level, nonverbal intelligence, and mLNT speech perception scores) accounted for 66.72% of the variance in CELF-P scores. Total intervention hours predicted significant added variance above and beyond these control variables, adding 5.85% to the total variance accounted for in CELF-P (total predicted variance = 71.57%). Better preschool language was independently associated with a younger age of fitting a HA, higher nonverbal intelligence, better early speech perception, and more hours of Moog Center intervention between birth and 36 months. Unaided PTA threshold (500, 1K, 2K) and mother's education level did not contribute statistically significantly to overall variance in CELF-P scores. None of the interactions among predictor variables was statistically significant, and the collective contribution of interactions was not statistically significant.

The regression model coefficients were used to obtain expected CELF-P scores as a function of total intervention hours, and results are plotted in Figure 2. The diagonal solid line represents the mean predicted CELF-P score with the other predictor variables set at their sample means.[1] The function is linear, and the point at which the line crosses the 85 standard score (the cutoff corresponding to one SD below the normative mean) is equal to 187 hours, indicating that half of the cases from any new sample can be expected to achieve a standard score of 85 at 187 hours of intervention. The shaded area around the prediction line is the 95% confidence band, providing an indication of the variability arising from the regression model.

**Table 4**
***Factors Predictive of CELF-P Scores***

| | *Vocabulary/Language* | | |
|---|---|---|---|
| *Predictors* | Standard Coefficient | *F*-ratio | *p* |
| PTA Threshold | -0.06 | -1.04 | 0.306 |
| Age at First HA | -0.36 | -2.62 | 0.012 |
| Mother's Education | 0.46 | 0.65 | 0.517 |
| Performance IQ | 0.38 | 3.32 | 0.002 |
| mLNT % Correct | 0.25 | 3.29 | 0.002 |
| Total Intervention Hours | 0.03 | 2.97 | 0.005 |
| Explained Variance | *71.57%* | | *df = (1,43)* |

*Note.* PTA = Pure Tone Average; HA = Hearing Aid; mLNT = Multi-syllabic Lexical Neighborhood Test

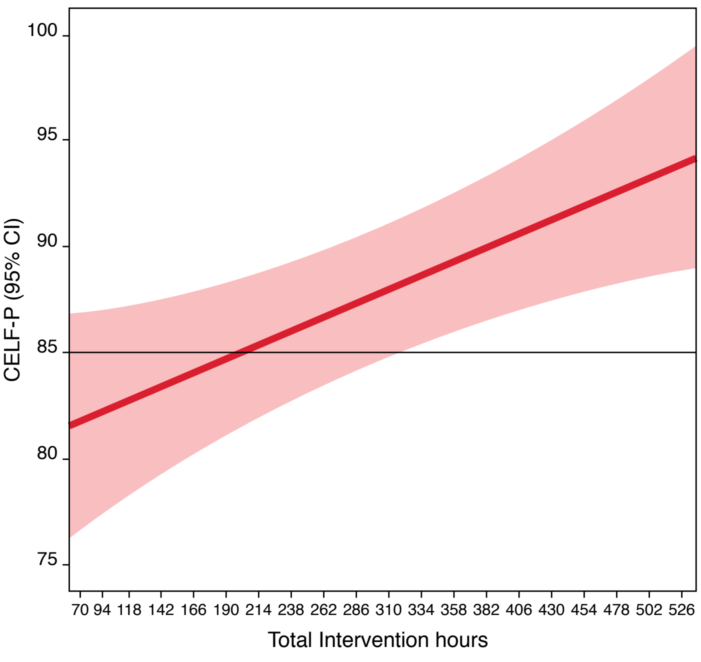


***Figure 2.*** **Predicted standard score on the Clinical Evaluation of Language Function-Preschool Test (CELF-P).** Control variables (unaided pure tone average threshold, age at first hearing aid, mother's education level, nonverbal intelligence, and speech perception scores) are set at the sample mean and plotted by total hours of intervention provided at the Moog Center between 0 and 36 months of age. The diagonal line represents the predicted mean and the shaded area around the prediction line is the 95% confidence band, providing an indication of the variability arising from the regression model.

[1]Predictors are correlated and some combinations implied in the graph may not be realistic. For example, age at first HA is highly correlated with total intervention hours, which means assuming mean age at first HA at all levels of total intervention hours does not fully match the underlying data. That is one reason the confidence intervals get wider at the extremes; they account for uncertainty in regions for which there is less information

**Question 3: What levels of speech perception, vocabulary, language, verbal reasoning, and reading were achieved at or near the end of elementary school?**

Table 5 summarizes results obtained on a battery of tests administered to the same 50 children when most were near the end of elementary school (average chronological age = 10.5 years). Both nonverbal (100.3) and verbal (97.2) composite scores on the WISC-V intelligence scale were within the average range, and there was no statistically significant gap between verbal (97) and nonverbal (101) index scores, indicating that these children were realizing their nonverbal potential in verbal reasoning skills. Average scores on the CASL (96.8) and the PPVT (97.5) were within one SD of hearing age-mates (> 85), as were reading scores on both the WRMT (100.2) and the TORC (102.7). Table 5 also summarizes the percent of the sample scoring 85 or higher on each test, ranging from 68% on the CASL global language measure to 92% on nonverbal intelligence. Scores within age-expectation were achieved by more than 75% of the sample for PPVT vocabulary and reading on the WRMT and the TORC.

Average speech perception scores are also presented in Table 5. Mean open-set word recognition on the LNT test was 87%, approaching the ceiling of the test. Scores on the BKB-SIN test indicated that, on average, children understood half of the sentence material when the speech exceeded the noise by 5.3 dB (signal-to-noise ratio). Post-hoc comparisons of speech perception scores for HA ($n$ = 15) and CI ($n$ = 35) users indicated a statistically significant advantage for HA users in word recognition scores in quiet with LNT mean = 84% for CI and 94% for HA users ($F$ = 4.25; $p$ = .045). HA users also exhibited statistically significantly lower (i.e., better) SNR ratio on the BKB-SIN (mean = 2.7 dB) compared to CI users (mean = 6.36 dB; $F$ = 7.46; $p$ =.009).

Mean of subscale score and associated 95% confidence intervals are presented in Figures 3 and 4 for WISC-V and CASL tests, respectively. Average subscale scores were within the average range for hearing age-mates and did not differ statistically significantly from one another except for higher standardized scores for the Visual-Spatial Scale ($M$ = 105) than Working Memory Scale ($M$ = 97; $F(1,48)$ = 4.71, $p$ = .04). CASL mean subtest scores were also within normal limits for age, but with statistically significantly lower scores on the Syntax ($F$ = 12.86; $p$ < .0001) and the Pragmatics ($F$ = 32.63; $p$ < .0001) subtests.

Average reading subtest scores are presented in Figure 5 for the WRMT and in Figure 6 for the TORC. All of the mean subtest standard scores on the WRMT fell within the average range for hearing age-mates, and no statistically significant differences were observed between decoding skills (word identification, word attack) and comprehension (word comprehension, passage comprehension).

All subtest means on the TORC were within the average range for hearing age-mates, but with higher subtest scores on Text Comprehension and Paragraph Construction compared to Contextual Fluency, Sentence Completion, and Relational Vocabulary. Text Comprehension is a subtest where students are given a list of questions prior to reading a passage, then tasked with answering the questions after silently reading the passage. Paragraph Construction measures the ability to reasonably construct a meaningful paragraph when given a list of sentences in random order. Thus, it appears that these children excel at comprehending connected text.

TORC scaled scores were statistically significantly lower on tasks tapping vocabulary and syntactic knowledge ($F$ = 58.3; $p$ < .0001). Contextual Fluency is a timed subtest of progressive difficulty, where students are given

**Table 5**
***Average Performance at the End of Elementary School***

| | *Mean* | *Standard Deviation* | *Range* | *% Within Normal Limits (WNL)* |
|---|---|---|---|---|
| Nonverbal Quotient (WISC-V) | 100.3 | 14.1 | 74–132 | 92 |
| Verbal Comprehension Index (WISC-V) | 97.2 | 16.4 | 70–136 | 72 |
| CASL – Standard Score (SS) | 96.8 | 18.0 | 66–136 | 68 |
| PPVT – SS | 97.5 | 17.8 | 55–132 | 80 |
| WRMT – Basic Skills SS | 97.5 | 15.1 | 63–134 | 84 |
| WRMT – Comprehension SS | 100.2 | 17.4 | 73–140 | 76 |
| TORC – SS | 102.7 | 18.4 | 54–144 | 86 |
| LNT % Correct | 87.1 | 16.0 | 22–100 | n/a |
| BKB-SIN (SNR) | 5.3 | 4.6 | -1–22 | n/a |

*Note.* WISC-V = Wechsler Intelligence Scale for Children; CASL = Comprehensive Assessment of Spoken Language; PPVT = Peabody Picture Vocabulary Test; WRMT = Woodcock Reading Mystery Test; TORC = Test of Reading Comprehension; LNT = Lexical Neighborhood Test; BKB-Sin = Bamford-Kowal-Bench Speech in Noise.

strings of text containing words in uppercase print without spaces or punctuation. As a measure of their knowledge of words in context, the students must identify as many words as they can by drawing a line between words. Relational Vocabulary measures the student's ability to identify related words using two lists of words. The first list contains three related words and the second list contains four words with two words related to the first list and two unrelated words. The student must then select the two related words from the second list that relate to the first list of related words. Sentence Completion is a task where the student must fill in a sentence missing two words with the correct word pairs chosen from a list of word pairs.

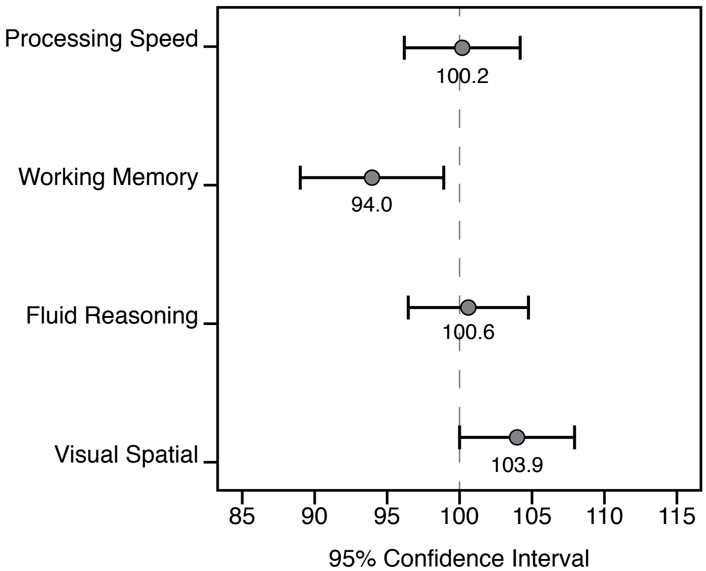


***Figure 3.*** **Average subscale standard scores on the Wechsler Intelligence Scale for Children (5th Edition; WISC-V).** Scores are plotted for 50 alumni of the Moog Center in elementary grades. Error bars around each mean represent the 95% confidence interval.

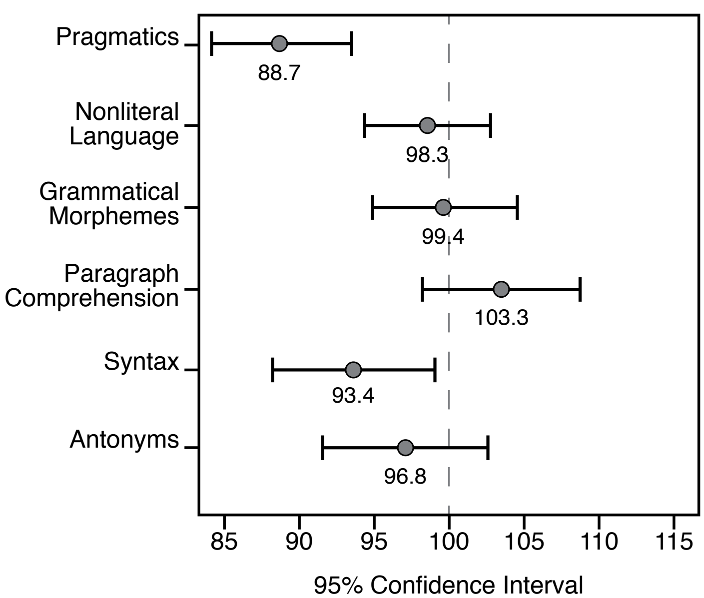


***Figure 4.*** **Average subtest standard scores on the Comprehensive Assessment of Spoken Language (CASL).** Scores are plotted for 50 alumni of the Moog Center in elementary grades. Error bars represent the 95% confidence interval.

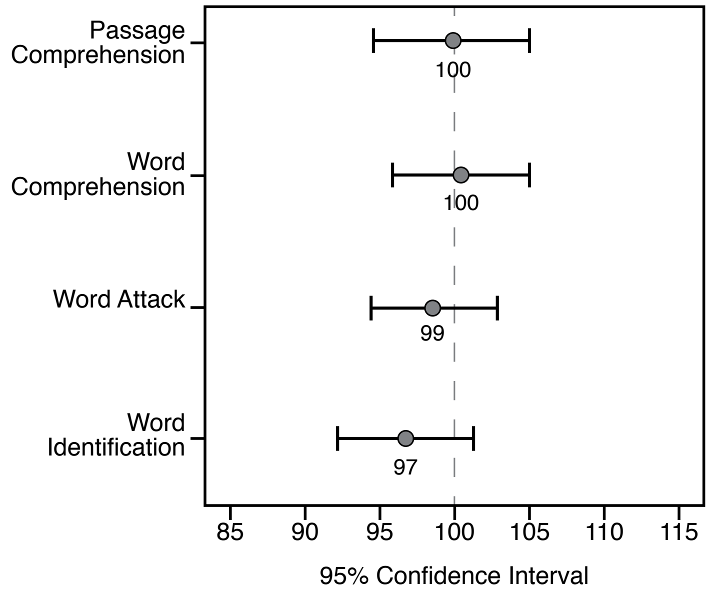


***Figure 5.*** **Average subtest standard score on the Woodcock Reading Mastery Test (WRMT).** Scores are plotted for 50 alumni of the Moog Center in elementary grades. Error bars represent the 95% confidence interval.

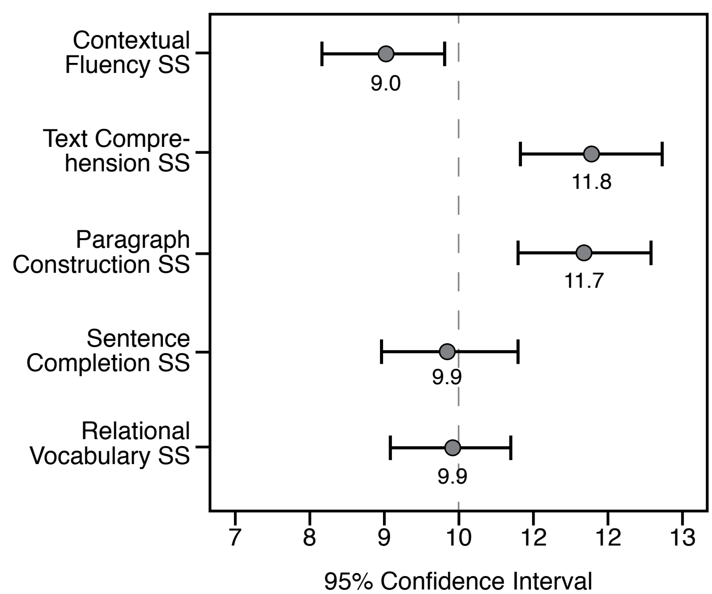


***Figure 6.*** **Average scaled scores (SS) on the Test of Reading Comprehension (TORC).** The average score for each subtest on the TORC is 10, with a range of 7–13. Scores are plotted for 50 alumni of the Moog Center in elementary grades. Error bars represent the 95% confidence interval.

**Table 6**
*Correlations*

| | LNT in Quiet | BKB-SIN | CASL std Score | WRMT Basic Skill | WRMT Read Comp | TORC Read Comp Index |
|---|---|---|---|---|---|---|
| Intervention Hours | 0.131 | -0.122 | .479** | 0.253 | .337* | .300* |
| | 0.363 | 0.399 | 0.000 | 0.076 | 0.017 | 0.034 |
| | 50 | 50 | 50 | 50 | 50 | 50 |
| Multisyllabic LNT easy words | .666** | -.385** | .298* | 0.029 | 0.106 | 0.146 |
| | 0.000 | 0.006 | 0.036 | 0.843 | 0.463 | 0.311 |
| | 50 | 50 | 50 | 50 | 50 | 50 |
| WISC NVIQ | 0.067 | 0.040 | .650** | .554** | .725** | .723** |
| | 0.642 | 0.782 | 0.000 | 0.000 | 0.000 | 0.000 |
| | 50 | 50 | 50 | 50 | 50 | 50 |
| Age at First HA | -0.033 | -0.102 | -.491** | -.361** | -.402** | -.371** |
| | 0.818 | 0.483 | 0.000 | 0.010 | 0.004 | 0.008 |
| | 50 | 50 | 50 | 50 | 50 | 50 |
| Unaided PTA | -.299* | .379** | -0.120 | -0.158 | -0.046 | -0.224 |
| | 0.035 | 0.007 | 0.407 | 0.274 | 0.752 | 0.117 |
| | 50 | 50 | 50 | 50 | 50 | 50 |

*Note.* WISC-V = Wechsler Intelligence Scale for Children; CASL = Comprehensive Assessment of Spoken Language; WRMT = Woodcock Reading Mastery Test; TORC = Test of Reading Comprehension; LNT = Lexical Neighborhood Test; BKB-SIN = Bamford-Kowal-Bench Speech in Noise; NVIQ = Nonverbal Intelligence; HA = Hearing Aid; PTA = Pure Tone Average.
*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.02 level (2-tailed).

**Question 4: Does intensity of Moog Center intervention between 0–36 months predict language and reading achievement in elementary school**?
Table 6 summarizes correlations between four predictor variables (Age at first HA, Nonverbal IQ, mLNT speech perception score, and Moog Center intervention hours) with the five language and reading outcomes measured in elementary school. Number of hours of Moog Center intervention (0–36 months) correlated $r = .479$ ($p < .001$) with language level, $r = .337$ ($p = .017$) with reading comprehension on the WRMT, and $r = .300$ ($p = .043$) with total score on the TORC.

To establish whether this relation remains strong after other predictor variables are controlled, multiple regression analyses were conducted to predict variance in CASL Total Language standard scores and WRMT total reading scores from four predictor variables: age at first HA, nonverbal IQ, mLNT speech perception scores in preschool, and total intervention hours 0–36 months of age. Results for the CASL appear in Table 7. Together with interactions, predictor variable accounted for 70% of total variance, with nonverbal IQ and total Moog Center intervention hours reaching statistical significance along with the interaction between mLNT speech perception and intervention hours. This result indicates that language scores in elementary school were associated with the child's cognitive ability and the amount of EI they received at the Moog Center. In addition, the statistically significant interaction between speech perception and intervention reflected the tendency

**Table 7**
*Factors Predictive of CASL Scores*

| | *Language* | | |
|---|---|---|---|
| *Predictors* | Standard Coefficient | *F*-ratio | *p* |
| Age at First HA | -0.23 | -1.29 | 0.203 |
| **Nonverbal IQ** | **0.72** | **5.08** | **< 0.001** |
| mLNT % Correct | 0.04 | 0.51 | 0.616 |
| **Total Intervention Hours** | **0.02** | **2.18** | **0.035** |
| Age at HA x Nonverbal IQ | 0.01 | -2.03 | 0.146 |
| **Age at HA x mLNT** | **-0.02** | **-2.03** | **0.050** |
| Age at HA x Inter. Hrs | 0.00 | -0.17 | 0.864 |
| NVIQ x mLNT | 0.01 | 1.22 | 0.230 |
| NVIQ x Interv. Hrs | 0.00 | 1.55 | 0.128 |
| **mLNT x Interv. Hrs** | **-0.01** | **-3.59** | **0.001** |
| *Explained Variance* | 70% | | *df = 1,39* |

*Note.* CASL = Comprehensive Assessment of Spoken Language; HA = Hearing Aid; mLNT = Multi-syllabic Lexical Neighborhood Test; NVIQ = Nonverbal Intelligence.
Boldface indicates significance.

for children with the poorest speech perception to benefit the most from intensive EI while those with high preschool speech perception benefitted the least.

Results of regression analysis to predict WRMT total reading scores are summarized in Table 8. Predictors accounted for 65% of the variance in reading scores. Nonverbal IQ was the only statistically significant predictor. In addition, the interaction between preschool speech perception and intervention hours was a statistically significant predictor of reading outcome, indicating that those with the poorest speech perception in preschool showed the most reading benefit from large doses of intervention during the 0 to 36 month period.

**Table 8**
***Factors Predictive of WRMT Scores***

| | *Language* | | |
|---|---|---|---|
| *Predictors* | Standard Coefficient | *F*-ratio | *p* |
| Age at First HA | -0.01 | -1.00 | 0.323 |
| **Nonverbal IQ** | **0.05** | **5.31** | **< 0.001** |
| mLNT % Correct | 0.01 | -1.15 | 0.256 |
| Total Intervention Hours | 0.00 | 1.11 | 0.275 |
| Age at HA x Nonverbal IQ | 0.01 | -2.03 | 0.146 |
| Age at HA x mLNT | 0.00 | 0.56 | 0.578 |
| Age at HA x Inter. Hrs | 0.00 | 0.68 | 0.498 |
| NVIQ x mLNT | 0.00 | 0.58 | 0.568 |
| NVIQ x Interv. Hrs | 0.0.00 | 1.12 | 0.272 |
| **mLNT x Interv. Hrs** | **-0.00** | **-2.51** | **0.016** |
| *Explained Variance* | 65% | | *df = 1,39* |

*Note.* HA = Hearing Aid; mLNT = Multi-syllabic Lexical Neighborhood Test; NVIQ = Nonverbal Intelligence; WRMT = Woodcock Reading Mastery Test. Boldface indicates significance.

## Summary

This study documents speech perception and language outcomes in preschool and elementary school and reading outcomes in elementary school for a group of 50 alumni representative of participants in the Moog Center for Deaf Education. The report describes levels of achievement at both ages and examines the effectiveness of the Moog Center EI program between birth and 36 months for later achievement. The following findings were supported by the data examined:

- Average language test scores at the end of preschool (or upon leaving the Moog Center) were within age-appropriate expectations for hearing children and remained at comparable levels when tested in elementary school.
- When the Moog Center alumni were assessed in elementary school, both their basic reading skills and reading comprehension levels were, on average, within age-appropriate expectations for hearing children. Both their verbal and nonverbal cognitive/reasoning abilities averaged within age-appropriate expectations for hearing children, with no statistically significant gap between verbal and nonverbal skill levels.
- HA users with moderate hearing loss did not differ from CI users with severe-profound hearing loss in their vocabulary comprehension, language, or reading scores, despite statistically significantly better unaided hearing thresholds and aided speech perception scores, especially in noise.
- Children with more hours of Moog Center intervention between 0 and 36 months of age achieved higher language scores at the end of preschool and in elementary school than children with less EI, after accounting for the positive effects of younger age at hearing aid fitting/ intervention, higher cognitive level, and better speech perception.
- Children with poorer speech perception levels in preschool received more benefit from greater amounts of EI at the Moog Center than did children with better speech perception levels. This benefit was apparent for both language and reading.

## Conclusions

For some children who are DHH, particularly those who are slow to develop aided auditory perception of speech, early intervention alone may not be sufficient to ensure age-appropriate spoken language development. For these children, the intensity of early (0–36 months) intervention provided at the Moog Center contributed significantly to long-term development of language and literacy over and above the benefits associated with the age at which intervention was initiated. The large dose of intervention provided by group instruction beginning as young as 18 months of age at the Moog Center is atypical for early intervention programs for children who are DHH, where parents are viewed as the child's primary teachers and intervention is focused on coaching them in language stimulation techniques. The results of this study are consistent with those reported by Moog and Geers, 2010, showing substantial language benefits from participation in a toddler class. This study extends those findings by (a) quantifying the number of hours of intervention provided and (b) following language outcomes into elementary grades and examining long-term benefits for learning to read. Because early educational intervention plays a vital role in language and academic success for children who are DHH, it is important to document the effects of the amount and intensity of intervention using a particular instructional approach. Further research is needed to assess the benefits of extending intensive intervention for children whose language delay persists beyond the preschool years, when children in LSL programs are often placed in regular education settings with hearing age-mates.

As in studies with other language-delayed populations, greater intervention intensity was more beneficial for some children than for others. Those children with poor aided speech perception scores in preschool exhibited the most benefit from early intensive intervention. Regardless, for all 50 alumni of the Moog Center, average language scores were within expectation for hearing children their age in preschool and remained within this range when they were assessed an average of four years later in elementary school grades. This longitudinal finding suggests that the early language foundation provided through intensive special education at the Moog Center continued to benefit these children through age-appropriate language and literacy in general classroom placement with their hearing age-mates.

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