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The Effects of Early Intervention on Language Growth after Age 3 for Children with Permanent Hearing Loss

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Abstract

Purpose: The overall goal of this study was to examine language performance in children with permanent hearing loss who were enrolled in a Listening and Spoken Language program. The influence of time spent in Early Intervention (EI) on language trajectories and ability to attain age-appropriate language skills was examined.

Method: Retrospective data were obtained from children ($N = 48$) who attended Central Institute for the Deaf (CID) for various lengths of time between 2004 and 2017. Children were grouped into those who had received EI prior to age 3 years versus those who did not. Standardized tests of receptive and expressive language were administered annually. Comparisons of language levels attained at the initial and final assessment were conducted and linear mixed model analyses examined language scores over time.

Results: Children receiving EI attained significantly higher levels of language than those receiving no EI. The rate of improvement over time in vocabulary scores was similar for both groups, however on a global language test that included morpho-syntax, children with EI made greater progress relative to age-matched peers than children without EI.

Conclusion: Children receiving EI exhibited a lasting advantage in the acquisition of spoken language over children who did not have access to EI.

Keywords: pediatric, early intervention, hearing loss, spoken language, hearing devices

Acronyms: BAHA = bone aided hearing aid; BI-CROS = Bilateral Contralateral Routing of Signal; CELF = Clinical Evaluation of Language Fundamentals; CI = cochlear implants; CID = Central Institute for the Deaf; EI = early intervention; EVT = Expressive Vocabulary Test; FM = Frequency Modulated; HA = hearing aid; HL = hearing loss; LSL = listening and spoken language; NBHS = newborn hearing screening; PHL = permanent hearing loss, PPVT = Peabody Picture Vocabulary Test; PTA = pure tone average; TH = typical hearing

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The overarching goal of Listening and Spoken Language (LSL) Early Intervention (EI) programs is to provide children with permanent hearing loss (PHL) the opportunity to develop spoken language skills that are commensurate with age-matched peers who have typical hearing (TH). These programs are a constellation of multidisciplinary services that include early hearing screening, confirmation of hearing loss, fitting and management of appropriate hearing technology and individualized family and small-group sessions for language instruction. The individualized sessions include optimizing language input by focusing on language acquisition, hearing loss, and hearing device use. Overall, exposure to newborn hearing screenings (NBHS) has had positive effects on language outcomes for children with PHL with the primary benefits related to early confirmation of hearing loss and subsequent receipt of hearing devices and services (Pimperton & Kennedy, 2012). In the United States, children with hearing loss have access to EI services from birth to 36 months through part C of the Individuals with Disabilities Educational Act (IDEA).

Prior to implementation of universal NBHS, Moeller (2000) found that children enrolled in EI services before 11 months of age had receptive language and verbal

reasoning skills that significantly exceeded those of children enrolled at later ages (range: 0.03–4.53 years) when tested at age 5. Subsequent studies examining the effects of various age at EI entry points (i.e., entry into EI by 3 months, 6 months, 24 months, etc.) on later spoken language (and in some cases, spoken language combined with signs or gestures) skills reveal positive outcomes related to earlier services (Ching et al., 2017; Meinzen-Derr et al., 2011; Vohr et al., 2011).

Studies that have examined the effects of EI using intensity of treatment as a metric have reached somewhat different conclusions. Geers et al. (2019) examined the effects of the amount of EI on spoken language and literacy outcomes for 50 children with PHL at preschool age and again at elementary age. Their variable of interest was the total hours (dose) of therapy in a listening and spoken language EI program (determined from billing records) between 0 and 36 months of age. They concluded that greater intensity of services during the birth to 36-month period was associated with higher spoken language and literacy scores at elementary age. These effects were apparent even after other contributing factors such as degree of hearing loss, nonverbal intelligence, and age at entry into services were controlled. Those children with poor early speech perception skills benefited the most from the increased dose provided by toddler classes beginning at 18 months. Alternatively, in a retrospective analysis of standardized receptive and expressive language scores of 40 children (mean age at test: 4.18 years) with cochlear implants (CIs), Chu et al. (2019) found that total dose of therapy, defined as the total number of parent-reported hours of therapy, was not associated with better spoken language outcomes. Moreover, for expressive language scores they found an inverse association between total dose of therapy and scores. That is, children with smaller total doses of intervention exhibited better language scores. These univariate analyses did not control for other contributing factors, such as hearing level, parent education, or intervention age. Notably, there was a significant association with age at CI and intensity of EI services, such that those children who received CIs at younger ages received less intensive services. Thus, those children receiving CIs at younger ages were likely to exhibit superior language skills and need less intensive therapy to achieve age-appropriate language levels.

Audiological interventions, such as confirmation of hearing loss and device fitting, typically co-occur with initiation of individual family sessions that focus on language instruction. Therefore, studies typically use variables such as age at hearing aid fit, age at confirmation of hearing loss, or age at CI as a proxy for initiation of EI services (Ching et al., 2018; Fulcher et al., 2012; Yoshinaga-Itano et al., 2018). The effects of educational intervention and audiological intervention are confounded in all of these studies, since they occur simultaneously in most rehabilitation settings.

In addition to the positive effects of EI factors, family, and child characteristics such as higher non-verbal intelligence, higher socio-economic status, less severe levels of hearing loss, female gender, and higher maternal education level contribute to positive outcomes for children with PHL (Ching et al., 2013; Ching et al., 2018; Wake et al., 2005; Yoshinago-Itano et al., 2018). These studies have examined the effects of EI on spoken language skills at specific time points such as preschool and elementary age (see also Daub et al., 2017). Tomblin and colleagues (2015) analyzed longitudinal data from 414 children with mild to moderate hearing impairment to test whether language growth trajectories were associated with degree of residual hearing and whether aided hearing influenced language growth in a systematic manner. The degree to which language skills fell behind those of age-matched peers with TH increased with greater severity of hearing loss. Early fitting of hearing aids was associated with better early language achievement, but children fit after 18 months of age improved in their language abilities as a function of the duration of hearing aid use. Greater language delays were reported in the domain of morpho-syntax (more dependent on auditory phoneme discrimination) than in semantic abilities (presumably less reliant on audition).

A number of variables contribute to children missing the opportunity to receive audiological and language instruction services during the first three years of life (late identification of hearing loss, loss to follow-up, inconsistent audiological results, family attendance). This is reflected in statistics that reveal that as many as 40% of children referred for follow up testing for hearing loss do not meet the recommended guidelines for early identification and intervention (Centers for Disease Control and Prevention, 2015). As such, these children may receive little, if any, EI services and begin intensive instruction in spoken language and listening after the age of three years. As might be expected, children with amounts of EI varying from none to a maximum of near-36 months, enter LSL programs with vastly different spoken language skills. Recently, Soman and Nevins (2018) proposed three different performance profiles of language growth for children entering LSL programs, those who *Keep Up, Catch Up,* or *Move Up.* In general, those in the *Keep Up* category have the benefit of meeting EI milestones and attain spoken language skills that are at or near their age-matched peers who have TH. The goal for these children is early entry into general education classrooms and maintenance of age-appropriate language skills for academic and linguistic success. Children in the *Catch Up* category typically start with language skills below their age-matched peers with TH as a result of little or no EI services, late identification of hearing loss, or late receipt of devices. However, with intensive instruction, many of these children show improvement in language skills and some ultimately achieve age-appropriate language skills. Those in the *Move Up* category may have secondary diagnoses (*e.g.*, attention deficit, learning disabilities) in addition to hearing loss that may preclude obtaining age-appropriate language skills. These children do, however, manage to make some progress and attain some

functional listening and communication skills (Soman & Nevins, 2018).

In the current study, the effects of EI during the birth to 36-month time period on longitudinal (*i.e.*, annual) development of spoken language skills was measured for children with PHL attending an intensive LSL program. A primary goal of this study was to understand the benefit associated with greater amount of time spent in an EI program that included coordinated audiological and language services after controlling for age, gender, maternal education, and degree of hearing loss.

Tests of vocabulary and global language (including semantics and morpho-syntax) were administered on a yearly basis for children ranging in age from 3 to 9 years. First, overall language levels were determined for all children in the study. Second, language growth trajectories were compared for children who received some amount of EI services during the birth to 36-month EI period and those who received no EI services in that age range. Third, for the group that received some period of EI services, the effects of duration of time spent in EI were examined. Finally, differential effects of EI on vocabulary compared to global language skills were explored.

Language development of children with PHL in the following areas was examined: (a) attainment of age-appropriate language levels, (b) effects of maternal education, gender, and hearing level on language, (c) improvement of language skills with age relative to age-matched peers with TH, and (d) effects of EI on language level and language growth rates with age.

Method

Retrospective data were obtained from children ($N = 48$) who attended the school-age program at CID for various lengths of time between 2004 and 2017. Typical of all LSL programs, CID emphasizes intensive listening and spoken language instruction (Bradham et al., 2018; Estes, 2010; Soman & Nevins, 2018) beginning as young as possible. The EI programs serve children from diagnosis of hearing loss (HL) through 36 months of age. The school program at CID serves children starting at age 3 years and emphasizes individualized spoken language instruction, literacy, and social skills as well as age-appropriate academic instruction.

Participants

Table 1 describes sample demographics for the total group of 48 children, including maternal education, gender, unaided pure-tone average (PTA; 0.5, 1 & 2 kHz) for the better ear, age at hearing aid (HA) fitting and age the child enrolled in the school program at CID. In this study, we report age at HA fitting as opposed to age at confirmation of hearing loss, since age at HA fitting represents the initiation of access to sound. On average these children were fit with HAs at 18.7 months ($SD = 14.4$ months) with an average unaided PTA for the better ear of 66 dB HL. The average maternal education calculated as total years of education through college and beyond, was 13 years. Forty-four percent of the group were female, and the average age enrolled in the CID school was 3.8 years ($SD = 1.2$ years). The devices worn during the time attending CID school were as follows: 15 children wore two cochlear implants (CI), 13 wore binaural HAs, 11 wore a CI and a HA at the non-implanted ear (bimodal devices), 3 wore Bone Anchored Hearing Aid (BAHA), 3 used a Frequency Modulated device (FM), 2 wore a combination of HA/FM, and 1 wore a bilateral contralateral routing of signal device (BI-CROS).

Table 1
Demographics of Children

Demographics ($N = 48$)	Mean	Standard Deviation	Range
Age at First Hearing Aid Fitting (months)	18.7	14.4	2–60
Maternal Education (years)	13.8	2.3	11–18
Unaided Pure Tone Average (Better Ear)	66.4	32.2	10–115
Age Began Central Institute for the Deaf School (years)	3.8	1.2	2.9–7.5
	Count (%)	Count (%)	
Gender	Female – 21 (44%)	Male – 27 (56%)	

Children were categorized into those who had received EI services during a period from birth to 36 months ($n = 32$) and those who did not receive EI ($n = 16$). Demographic characteristics of each group are in Tables 2a and 2b. The EI service model included confirmation of hearing loss and monitoring of hearing thresholds, provision and monitoring of hearing devices (i.e., HAs, CIs, FM, BAHA, BI-CROS) and instruction for families related to hearing loss and acquisition of language. Typical of most LSL programs,

Table 2a
Demographics of Students with Early Intervention Services

Demographics ($n = 32$)	Mean	Standard Deviation	Range
Age at First Hearing Aid Fitting (months)	12.4	8.8	2–28
Maternal Education (years)	13.8	2.2	11–18
Unaided Pure Tone Average (Better Ear)	63.0	35.5	10–115
Age Began Central Institute for the Deaf School (years)	3.3	0.5	2.9–4.9
Duration of Early Intervention (months)	22.3	9.6	3–34
	Count (%)	Count (%)	
Gender	Female – 11 (34%)	Male – 21 (66%)	

Table 2b

Demographics of Students with no Early Intervention Services

Demographics (n = 16)	Mean	Standard Deviation	Range
Age at First Hearing Aid Fitting (months)	30.9	15.5	3–60
Maternal Education (years)	13.8	2.5	11–18
Unaided Pure Tone Average (Better Ear)	73.3	23.7	31–115
Age Began Central Institute for the Deaf School (years)	4.9	1.5	3.0–7.5
	Count (%)	Count (%)	
Gender	Female – 10 (62%)	Male – 6 (38%)	

the EI program at CID involves a multidisciplinary team of audiologists, teachers of the deaf and speech language pathologists specializing in developing listening and spoken language skills through device use and instructional strategies. For children attending CID during the time period listed above (2004–2017), the frequency of sessions with teachers of the deaf and speech language pathologists varied depending on the age of the child and the needs of the family. These sessions were conducted primarily through home visits, although some used a combination of homebased and center-based therapy depending on distance from the facility. Some small group instruction was included for children beginning at 24 months of age. The duration in EI was the number of months enrolled in EI services through 36 months of age. Most children were fit with HAs within 1 to 2 months of enrolling in EI services. The duration of time spent in EI varied from 3 months to 34 months (mean = 22 months). Children entered the CID school at an average age of 3.3 years. Most were enrolled near their 3rd birthday, however depending on the academic school calendar, some entered slightly before (~2.9 years). Four children entered the school at later ages (~4.0–4.9 years) due to a variety of family circumstances.

For children who did not receive EI services (n = 16), the average age of HA fitting was 31 months with a range from 3 months to 60 months. These participants entered the CID school at an average age of 4.9 years (SD = 1.5 years).

All children enrolled at CID receive norm-referenced standardized tests of receptive and expressive vocabulary and language annually. All measures were administered and scored according to the test manual by certified SLPs. The number of tests administered to a specific child varied based on student age at enrollment and length of enrollment. The average number of annual test sessions was 3 and ranged from 1–6.[1] The maximum age tested was 9 years old. The following tests were administered at each test session.

[1]One child had only one test session. In this case, the child's data point is used in the analysis to estimate the intercept.

Receptive Vocabulary

The Peabody Picture Vocabulary Test, Fourth Edition (PPVT-4; Dunn & Dunn, 2007), a measure of receptive vocabulary, was administered live voice in an auditory–visual mode. The examiner provided a target word and the child was asked to identify the correct picture from a closed set of 4 pictures.

Expressive Vocabulary

The Expressive Vocabulary Test, Second Edition (EVT-2; Williams, 2007), requires the child to provide either verbal labels or synonyms. The child is shown a colored picture and prompted by the examiner to provide a one-word response (e.g., "What is this animal?" or "Tell me another word for jacket.").

Receptive and Expressive Language

Depending on the child's age at test, either The Clinical Evaluation of Language Fundamentals Preschool-2 (CELF-P2; Wiig et al., 2004) or the Clinical Evaluation of Language Fundamentals–Fourth Edition (CELF–4; Semel et al., 2003) was administered to evaluate global language in both the receptive and expressive domains.

The CELF-P2 provides a core language score derived from three subtests: Sentence Structure, Word Structure, and Expressive Vocabulary. The Sentence Structure subtest evaluates a child's ability to understand and process sentence formation rules. The child chooses one of four pictures which best represents sentences read by the examiner. Sentences vary in length and complexity (Wiig et al., 2004, p. 15). The Word Structure subtest evaluates the child's ability to apply morphology rules and use appropriate pronouns. The child provides a missing word or phrase (e.g., preposition, pronoun, and various verb tense) in a sentence spoken by the examiner (Wiig et al., 2004, p. 18). The Expressive Vocabulary subtest evaluates the child's ability to provide an appropriate label to describe pictures of objects and actions (Wiig et al., 2004, p. 22).

The CELF-4 is a global measure of language skills and provides a core language score derived from four subtests for children ages 5 to 8: Concepts and Following Directions, Word Structure, Recalling Sentences, and Formulated Sentences. The Concepts and Following Directions subtest is used to evaluate the child's ability to interpret, recall, and execute oral directions of increasing length and syntactic complexity (Semel et al., 2003, p. 18). The Word Structure subtest evaluates a child's ability to apply morphology rules and use appropriate pronouns. The child provides a missing word or phrase in a sentence spoken by the examiner (Semel et al., 2003, p. 22). The Recalling Sentences subtest evaluates the child's ability to recall and reproduce sentences of varying length and syntactic complexity without altering word meanings, morphology or syntax. The child imitates sentences spoken by the examiner (Semel et al., 2003, p. 25). The Formulated Sentences subtest evaluates the child's ability to formulate compound and complex sentences

using target words or phrases, while using a picture as a reference (Semel et al., 2003, p. 33).

Data Analysis

Standardized scores were used to control for chronological age and compare a child's performance to that of their age-matched peers with TH in each test's normative sample. A standardized score of 100 reflects average age-appropriate performance, with a standard deviation of 15. Receptive vocabulary (PPVT), expressive vocabulary (EVT) and global language (Core Language Score from the CELF) scores from each successive annual evaluation were obtained from student records.

Linear mixed model analyses examined change in annual standardized language scores over time on a continuous rather than a fixed set of points and without having the same number of tests per subject. If a child makes age-appropriate progress over time, their standardized scores from year to year remain essentially the same. Thus, repeated assessments showing a year of language growth for an average hearing student would be shown by a flat line (i.e., a slope of zero). If the student makes more than yearly expected progress, the slope would be positive; if the child makes less than age-appropriate progress, the slope would be negative.

Predictor variables were entered in stages to test their independent contributions to language scores. Demographic variables were entered on the first step to determine the amount of variance in language outcome attributable to the child's gender, mother's education, degree of hearing loss (best-ear unaided PTA), and age at test. The categorical variable *Early Intervention* compared language levels achieved by those who received EI (coded as 2) and those who did not receive EI (coded as 1) after variance due to demographic variables had been accounted for in the first step. Duration of EI was entered as a continuous variable at subsequent stages to determine the effects of duration of EI within the group receiving services. Interactions between the EI variables of interest and age were also analyzed in subsequent steps of the regression. The sequential entry of variables was necessary to account for main effects of predictor variables before interpreting any interactions among variables of interest (age at test, receipt of EI services, and duration of EI). In these linear mixed models, age and the intercept were treated as random effects.

Results

The average age at the initial assessment was 4.57 years old and the average age at the final assessment was 6.75. Average language test scores are summarized in Table 3a, along with the percentage of children at each assessment session scoring within 1 *SD* of age-matched peers in the normative sample for each test. Pairwise comparisons of scores on each of the three measures are summarized in Table 3b. EVT scores were significantly higher than PPVT or CELF scores at both test sessions and scores on both vocabulary tests were significantly higher than scores on the global language measure (CELF). Mean language scores for the EI group ($n = 32$) and No EI group ($n = 16$) at the initial test and final test sessions are summarized separately in Table 4. Both groups made significant gains over time relative to age-matched peers with TH. Scores of the EI group exceeded those of the No EI group at both initial and final test sessions on all tests.

Table 3a

Test Scores

	Initial Test Session			Final Test Session		
Standard Scores*	Mean	Standard Deviation	%WNL	Mean	Standard Deviation	%WNL
PPVT	85.1	17.6	54	93.6	16.3	69
EVT	88.9	18.4	60	99.5	15.9	79
CELF	76.4	21.0	35	85.2	23.4	63

Note. There were 48 participants tested. WNL = within normal limits; PPVT = Peabody Picture Vocabulary Test; EVT = Expressive Vocabulary Test; CELF = Clinical Evaluation of Language Fundamentals.
*Mean = 100; Standard Deviation = 15

Table 3b

Language Tests Pairwise Comparisons

		First Test Session			Last Test Session		
		Mean Difference	Standard Error	$p <$	Mean Difference	Standard Error	$p <$
PPVT	EVT	-3.9	1.1	.018	-5.9	0.9	.001
PPVT	CELF	9.3	1.8	.001	10.1	1.5	.001
EVT	CELF	13.2	1.7	.001	16.0	1.5	.001

Note. PPVT = Peabody Picture Vocabulary Test; EVT = Expressive Vocabulary Test; CELF = Clinical Evaluation of Language Fundamentals

For the subsequent analyses, age at HA fitting is not included as a predictor variable. As one might expect age at HA fitting and duration of EI services were highly correlated ($r = .68$) since most children received their HAs when they entered EI, thus age at HA was not included in the demographic predictors.

The regression coefficients; standard error; *t* values; and significance values for the PPVT, EVT, and CELF language scores are shown in Table 5 (sections 5a, 5b and 5c respectively). The graphs in Figures 1–3 illustrate the relationship between each outcome variable (PPVT, EVT, and CELF Language respectively) score and age for the EI groups. The predicted average scores and 95th percent confidence intervals (CEIs) from the model are plotted over ranges that represent the median first and last ages tested for each group. The No EI group is labeled and shown in green. To illustrate the effects of duration of intervention for the EI group, the duration variable is divided into two levels based on a standard deviation below and above the mean duration of intervention in months ($M = 22.3$ months, $SD = 9.6$ months). The groups are labeled Low Duration EI and High Duration EI and shown in blue and red, respectively.

Table 4

Standard Test Scores for Early Intervention and No Early Intervention Groups*

		Early Intervention (n = 32)		No Early Intervention (n = 16)	
		Initial	Final	Initial	Final
Age (years)	Mean	3.57	5.75	5.57	7.57
	SD	0.69	1.37	1.40	1.34
PPVT	Mean	92.1	99.2	72.6	82.3
	SD	13.5	14.8	16.0	
	%WNL	72	88	19	31
	15.5	13.5	14.8	16.0	88.4
	%WNL	72	88	19	31
EVT	Mean	96.4	105.0	76.8	88.4
	SD	18.2	13.2	12.9	15.5
	%WNL	78	91	25	56
CELF	Mean	83.7	94.2	61.6	67.1
	SD	19.7	18.6	14.4	21.9
	%WNL	50	81	6	25

Note. WNL = within normal limits; PPVT = Peabody Picture Vocabulary Test; EVT = Expressive Vocabulary Test; CELF = Clinical Evaluation of Language Fundamentals.
*Mean = 100; Standard Deviation = 15

Table 5a

Peabody Picture Vocabulary Test

Predictor	Coefficient	Std Error	df	*t*-value	*p*-value
Intercept	85.18	15.3	38.0	5.56	.0001
Gender	-3.76	5.0	37.5	-0.76	.45
Mom's Education (in years)	1.49	1.1	37.3	1.34	.18
Better Ear unaided PTA	*-0.26*	*0.1*	*38.8*	*-3.28*	***.002***
Age	*2.16*	*0.7*	*31.2*	*3.21*	***.003***
EI-Yes	*20.3*	*5.1*	*40.2*	*3.97*	***.0003***
Age x EI-Yes	-0.48	1.4	32.4	-0.34	.73
EI-Yes x duration of EI	0.51	0.3	36.6	1.96	.058
Age Squared	*-1.06*	*0.3*	*98.5*	*-3.99*	***.0001***
Age x EI-Yes x duration of EI	-0.08	.09	36.7	-0.84	.41
EI-Yes x Age Squared x duration of EI	-0.03	.03	96.4	-1.33	.19

Note. The regression model summary has 48 subjects. EI= Early Intervention, PTA= Puretone Average, Std = standard, df = degrees of freedom. Bold text indicates statistically significant variables in the model.

Table 5b

Expressive Vocabulary Test

Predictor	Coefficient	Std Error	df	*t*-value	*p*-value
Intercept	84.82	16.4	36.8	5.18	.0001
Gender	-1.20	5.3	35.2	-0.23	.82
Mom's Education (in years)	1.63	1.2	34.7	1.39	.17
Better Ear unaided PTA	-0.25	0.1	37.6	-2.95	**.01**
Age	2.64	0.8	30.9	3.46	**.002**
EI-Yes	20.65	5.4	35.0	3.80	**.001**
Age x EI-Yes	-1.13	1.6	31.9	-0.72	.48
EI-Yes x duration of EI	0.70	0.3	36.7	2.46	**.02**
Age Squared	-1.12	0.3	99.6	-3.93	**.0002**
Age x EI-Yes x duration of EI	-0.20	0.1	35.2	-2.13	**.04**
EI-Yes x Age Squared x duration of EI	0.02	.03	90.4	0.67	.50

Note. The regression model summary has 48 subjects. EI = Early Intervention, PTA= Puretone Average, Std = standard, df = degrees of freedom. Bold text indicates statistically significant variables in the model.

Table 5c

Comprehensive Evaluation of Language Fundamentals

Predictor	Coefficient	Std Error	df	*t*-value	*p*-value
Intercept	72.08	18.4	40.1	3.91	.0003
Gender	-1.49	6.0	41.0	-0.25	.81
Mom's Education (in years)	1.76	1.4	42.2	1.29	.20
Better Ear unaided PTA	-0.25	0.1	40.7	-2.66	**.01**
Age	2.32	0.9	29.5	2.55	**.02**
EI-Yes	24.07	6.4	46.2	3.75	**.001**
Age x EI-Yes	3.76	1.8	27.9	2.11	**.04**
EI-Yes x duration of EI	0.88	0.3	38.1	2.89	**.01**
Age Squared	-0.54	0.3	103.2	-1.72	.09
Age x EI-Yes x duration of EI	-0.04	0.1	31.1	-0.37	.71
EI-Yes x Age Squared x duration of EI	-0.01	0.03	102.3	-0.18	.86

Note. The regression model summary has 48 subjects. EI = Early Intervention, PTA= Puretone Average, Std = standard, df = degrees of freedom. Bold text indicates statistically significant variables in the model.

Receptive Vocabulary (PPVT)

The regression analyses for the PPVT revealed the following:

EI and No EI Groups ($N = 48$)

Step 1: Age at test and better ear unaided PTA were significant predictors of receptive vocabulary level ($p = .003$ and $p = .002$ respectively). Increases in age at test had a positive effect on PPVT standard score (children closed the vocabulary gap with age-matched peers with TH in the normative sample as they got older) and increases in PTA (poorer hearing) had a negative effect on scores. Children with greater hearing losses were further behind age-matched peers with TH in vocabulary development.

Step 2: The EI categorical variable (EI group vs. No EI group) was a significant predictor of vocabulary level after controlling for demographic variables entered at the first step of the analysis. Children in the EI group scored approximately 20 standard score points higher than those without EI, a significant difference ($p = .0003$).

Step 3: There was no significant interaction between test age and EI group indicating that the growth of receptive vocabulary relative to age-matched peers with TH is similar in both EI and No EI groups.

Step 4: The quadratic effect of age (age squared) at test was significant and negative ($p < .01$) showing that the standard score gains associated with increasing age diminish as age increases (i.e., rate of change over time levels off).

EI Group ($n = 32$)

Step 5: The effect of duration of intervention on PPVT scores within the EI group did not meet statistical significance ($p = .058$).

Steps 6 & 7: There were no significant interactions between age (linear or quadratic) and duration of EI within the group that received EI. The effects of age do not change with duration of EI.

The graph in Figure 1 illustrates the relationship between PPVT score and age for the EI groups. Note that the EI group achieves overall higher scores than the No EI group, however receptive vocabulary growth is similar for both groups.

Expressive Vocabulary (EVT)

The regression analyses for the EVT scores revealed the following:

EI and No EI Groups ($N = 48$)

Step 1: Age at test and better ear unaided PTA were significant predictors of EVT scores ($p = .002$ and $p = .01$ respectively) in the model. Increases in age at test had a positive effect on EVT standard score (children closed the vocabulary gap with age-matched peers with TH in the normative sample as they got older) and increases in PTA had a negative effect on scores. Children with greater hearing losses were further behind in expressive vocabulary development.

Step 2: After controlling for demographic variables, the EI categorical variable (EI group vs. No EI group) was a significant predictor of vocabulary level. Children in the EI group scored approximately 21 standard score points higher than those in the group without EI, a significant difference ($p = .001$).

Step 3: The interaction between EI group and age was not significant indicating that the rate of standard score change with age was not different between the EI and No EI groups.

Step 4: The quadratic effect of age (age squared) at test was significant ($p = .002$) indicating that the linear effect of age diminishes as age increases.

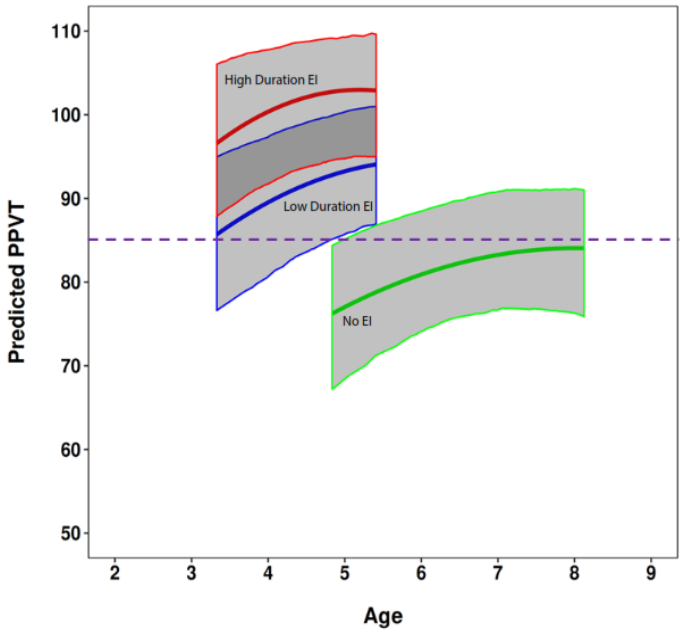
EI Group ($n = 32$)

Step 5: The duration effect within the EI group was significant ($p = .02$) indicating that for those who received some EI services, longer durations of EI resulted in better expressive vocabulary skills.

Steps 6 & 7: The linear effects of age and duration of EI within the EI group were significant ($p = .04$) indicating that the effects of duration of intervention diminish as age increases. The non-linear effects of age and duration of EI were not significant.

Figure 1

Peabody Picture Vocabulary Test (PPVT) Standard Scores

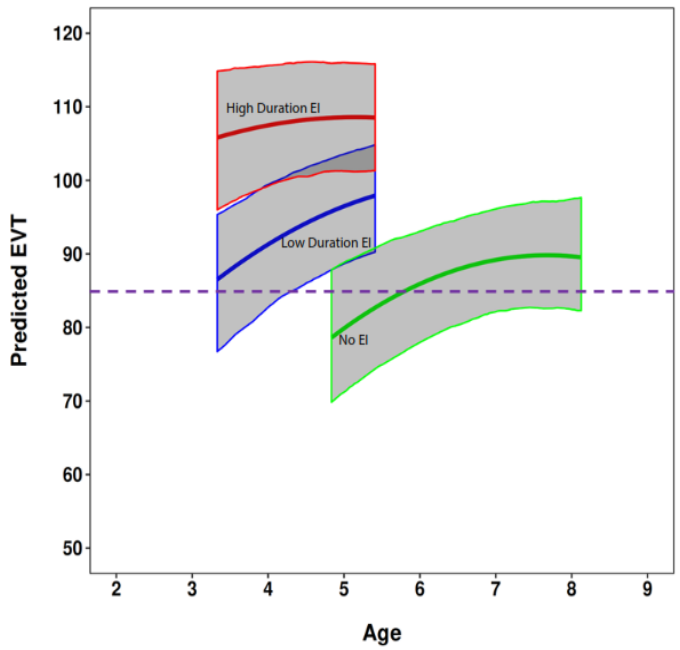


Note. PPVT standard scores are shown on the Y axis as a function of age at test in years on the X axis for the No Early Intervention (EI) Group, Low Duration EI Group and High Duration EI Groups (green, blue, and red respectively). The 95th percent confidence intervals are illustrated by gray shaded areas. The dashed line illustrates the minimum standard score (85) for the normative range.

The graph in Figure 2 illustrates the relationship between EVT and test age for the EI groups. Attendance in EI programs leads to higher expressive vocabulary scores as shown by the overall differences in the predicted absolute EVT standard score for the No EI group compared to the Low and High Duration EI groups. Overall, scores on the EVT increase with age, but eventually plateau. Within the EI group, longer duration of early intervention leads to better outcomes for expressive vocabulary. Expressive vocabulary growth over time was reflected in the duration of EI by age interaction within the EI group. Those children in the High Duration EI group started with overall higher EVT scores that plateaued with increasing age, while those in the Low Duration EI group started with lower overall scores and showed a linear increase in scores with increasing age.

Figure 2

Expressive Vocabulary Test (EVT) Standard Scores



Note. Expressive Vocabulary Test (EVT) standard scores are shown on the Y axis as a function of age at test in years on the X axis for No Early Intervention (EI), Low Duration EI, and High Duration EI groups (green, red, and blue respectively). The 95th percent confidence intervals are illustrated by gray shaded areas. The dashed line illustrates the minimum standard score (85) for the normative range.

Global Language (CELF)

The regression analyses revealed the following:

EI and No EI Groups ($N = 48$)

Step 1: Age at test and better ear unaided PTA were significant predictors ($p = .02$ and $p = .001$ respectively) in the model. Increases in age at test had a positive effect on CELF standard scores (children's language skills more closely approximated age-matched peers who have TH in the normative sample as they got older) and increases in PTA had a negative effect on scores. Children with greater hearing losses were further behind in language development.

Step 2: After controlling for demographic variables entered at the first step of the analysis, the EI categorical variable (EI group vs. No EI group) was a significant predictor. Children in the EI group scored approximately 24 standard score points higher than those in the group without EI, resulting in a significant difference between means ($p = .001$).

Step 3: The interaction between EI group and age was significant ($p = .04$) indicating that improvement in language scores over time were greater for the EI group vs. the No EI group.

Step 4: The quadratic effect of age (age squared) at test was not significant indicating that language gains over time did not plateau.

EI Group ($n = 32$)

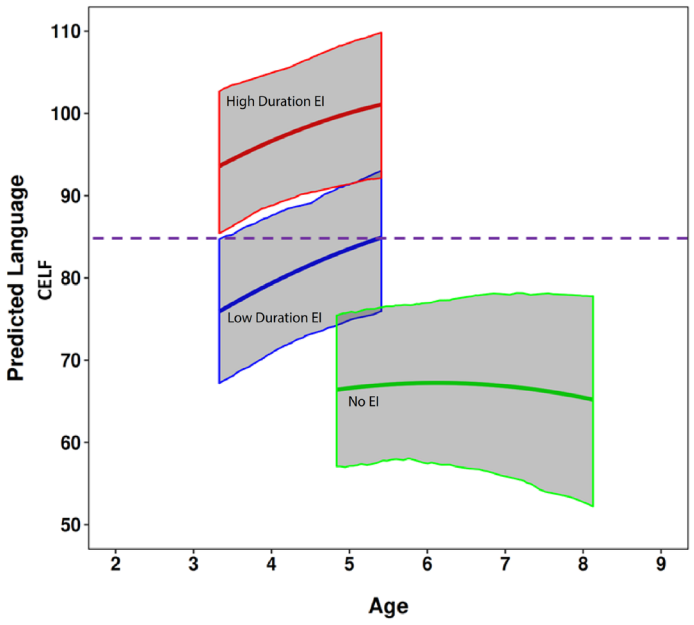
Step 5: The duration effect within the EI group was significant ($p = .01$) indicating that for those in the EI group, longer durations of early intervention resulted in better language skills.

Step 6: The interaction of age and duration of EI within the EI group was not significant. The rate of language growth over time was similar regardless of duration of EI.

Step 7: The interaction between EI duration and the quadratic effect of age of duration was not significant meaning that language growth did not plateau with increased duration of EI.

Figure 3

Clinical Evaluation of Language Fundamentals (CELF) Standard Scores



Note. CELF standard scores are shown on the Y axis as a function of age at test in years on the X axis for the No Early Intervention (EI) Group, Low Duration EI Group and High Duration EI Groups (green, blue, and red respectively). The 95th percent confidence intervals are illustrated by gray shaded areas. The dashed line illustrates the minimum standard score (85) for the normative range.

The graph in Figure 3 illustrates the relationship between CELF scores and age for the EI groups. As noted in these graphs, attendance in an EI program leads to higher language scores as shown by the overall differences in the predicted absolute CELF standard score for the No EI group compared to the Low Duration and High Duration EI groups. The effects of age are more apparent for the EI group as evidenced by the steeper increase in CELF scores over time for both the Low or High Duration EI groups compared to the No EI group.

Discussion

The overall goal of this retrospective study was to examine language growth profiles in children with PHL enrolled in a LSL program. Specifically, the influence of time spent in EI programs (birth to 36 months) on these children's language trajectories and ability to attain age-appropriate language skills were examined. Prior to enrolling in CID's school program, some children had spent varying amounts of time in an EI program where they received the benefit of early audiological management coupled with individual spoken language instruction. Due to a variety of reasons (e.g., loss to follow-up from NBHS, late confirmation of hearing loss) some children had received no EI services prior to enrolling into the CID school. A second aim of this study was to determine if the effects of EI were consistent across various language domains including receptive vocabulary, expressive vocabulary, and global language skills. The following questions were addressed in the data analysis:

Do scores of children with PHL reach age-appropriate levels during their years of enrollment in a LSL education program?

As a group, the average scores from these children with PHL were within 1 *SD* of age-matched peers with TH (i.e., within the normative test range, 85–115) in expressive and receptive vocabulary but not in global language skills at their initial assessment (mean age 4.5 years). Average scores at the last assessment (mean age 6.6) were within the normative range on all three measures. As noted in Table 3a, average performance for the EVT (standard score = 99.5) more closely approximated age-matched peers with TH (standard score = 100) than receptive vocabulary (93.6) and global language skills (85.2) at the last assessment.

Do language scores for children with PHL improve with age?

Across all measures of language, there was a significant trend for their language delay to diminish over time. This trend reflects the positive effect of enrollment in an LSL education setting throughout the age range represented in the sample.

Do language scores improve with greater residual hearing?

Across all measures of language, children with greater amounts of residual hearing scored closer to age-matched peers with TH. The overall effects of residual hearing level are consistent with studies examining benefits of EI (Ching et al., 2017; Tomblin et al., 2015; Vohr et al., 2011). However, unaided PTA did not interact with test age, EI status, or duration of EI. The positive effects of longer duration of intervention on language were similar regardless of degree of hearing loss. This finding stands in contrast to earlier results showing that children with greater hearing loss benefitted more from greater doses of early intervention (Geers et al., 2019). This apparent contradiction may be associated with the different measures of EI, number of months enrolled compared to number of hours participated.

Are language scores affected by level of maternal education and by the child's gender?

Unlike results observed in some other samples reported in the literature (Ching et al., 2018; Yoshinaga-Itano et al., 2018; Tomblin et al., 2015) maternal education level did not contribute significantly to variance in language performance. The current finding may be attributable to the relatively high mean education level and low variability observed in this sample. In contrast to showing language benefits for females (Ching et al., 2013), the current study found no significant effects related to gender.

Do language scores improve with EI? How much advantage does EI provide?

After controlling for age and hearing loss, children who received some amount of EI performed closer to TH age-appropriate levels than children who did not receive EI. The advantage was similar across the three language measures, ranging from 20 to 24 standard score points, an increase of more than one standard deviation for age-norms. This advantage was apparent in initial language level measured when each child began attending the school at CID as well in the final assessment.

Do language scores improve with longer EI?

With the exception of receptive vocabulary, where group differences did not meet statistical significance, longer durations of EI were associated with expressive vocabulary scores and language scores closer to age-appropriate levels. Duration of EI was highly correlated with age at HA fitting, suggesting that these factors overlap in affecting language levels. Therefore, the advantage associated with EI is associated with younger access to the auditory speech signal through the use of technology as well as greater duration of guided instruction. There was no attempt in this study to disentangle the effects of cumulative early auditory access with hearing devices from time spent in guided language instruction. During the EI period, families receive information related to hearing device function, device limitations, troubleshooting techniques and promoting consistent device use. Concurrently, they receive guided instruction related to spoken language development and strategies to foster language skills. The authors suggest that these functions must occur in tandem for children to receive optimal spoken language outcomes.

Does language growth rate improve with EI?

The rate of improvement over time in receptive and expressive vocabulary scores is similar in trajectory for children with and without EI. This result indicates that intervention in the school at CID produced similar gains

in children who entered school scoring closer to age-appropriate levels after receiving EI and children who started school without EI and were thus further behind in language.

The results for the global language measure showed a different pattern. The children with EI exhibited substantial gains with age, while children without EI showed almost no change in standard score over time. While children with EI were in the process of catching up with age-matched peers with TH in global language skill, children without EI were maintaining a rate of growth similar to age-matched peers with TH, but without closing the gap. Tomblin et al. (2015) reported that the development of morpho-syntax was particularly susceptible to deficits for children with mild to severe hearing loss. We observe a similar trend in this study where children who did not receive EI were struggling to catch up with age-matched peers with TH when morpho-syntactic skills were included.

Does language growth rate plateau with age?

The growth of receptive and expressive vocabulary scores with age plateaus over time, due in part to a number of children scoring within age-appropriate levels and reaching ceiling performance while attending CID. There was no significant tendency for growth in global language skills to level off during this period, indicating that global language skills continued to improve substantially with years spent in intensive LSL education.

Do the effects of EI diminish with age?

The advantage of EI over No EI for receptive and expressive vocabulary scores got smaller as children aged. This indicates that the No EI group learned vocabulary at a faster rate than the EI group, so that the effects of EI diminished with age. However, for global language, the advantage of EI persisted throughout the age range measured for this study indicating lasting effects for early services.

Conclusion

Reaching spoken language levels commensurate with age-matched peers with TH facilitates academic success in a general education setting and is a primary goal of LSL intervention programs for children with PHL. Results from the CID sample indicate that achieving this objective depends on the severity of a child's hearing loss and how early auditory access to speech through amplification and spoken language intervention (typically occurring in tandem) are initiated. Regardless of their degree of hearing loss, children enrolled in EI before 3 years of age exhibited a lasting advantage in the acquisition of spoken language over children who did not have access to EI. Over 80% of children with EI reached language levels commensurate with age-matched peers who have TH by the time of their last test session (average age of 5.7 years). However, at an average age of 7.6 years, only 25% of students without EI caught up with age-matched peers with TH for global language, 31% for receptive, and 56% for expressive vocabulary respectively. Acquiring facility with English semantics, morphology, and syntax presented substantially greater difficulty than learning new vocabulary for students who did not receive EI. These global language skills contribute substantially to the development of reading comprehension, and therefore should receive increased instructional focus in intervention programs designed to prepare children with PHL for age-appropriate placement in regular education classrooms.

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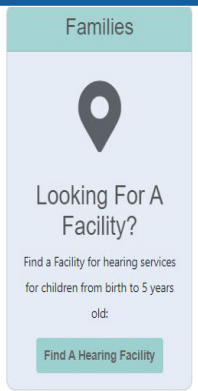
EHDInfo



Welcome to EHDI-PALS

This site links you to information, resources, and services for children with hearing loss. At the heart of EHDI-PALS is a national web-based directory of facilities that offer pediatric audiology services to young children who are younger than five years of age.

LEARN MORE about childhood hearing loss, hearing testing, and important questions parents can ask when making appointments. This contains great web resources for parents and professionals.

Find OTHER HELPFUL WEBSITES, including national and state parent support organizations and other resources.

You can also find out more about the EHDI-PALS Advisory Group.

To learn more about childhood hearing loss or if you need help throughout the screening, diagnosis and early intervention process, contact your state Early Hearing Detection and Intervention (EHDI) Coordinator to assist you.