Delayed Language Exposure Has a Negative Impact on Receptive Vocabulary Skills in Deaf and Hard of Hearing Children despite Early Use of Hearing Technology

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1. Introduction

Early childhood is a critical period for language acquisition (Johnson & Newport, 1989; Newport 1990), thus, access to fluent language from birth is paramount for language development (e.g., Levine et al., 2016). However, most deaf and hard of hearing children are born to hearing, non-signing parents (Mitchell & Karchmer, 2004), and as a result do not have full, immediate access to their linguistic environment. When parents first discover their child's deafness, many are encouraged by clinicians toward a language acquisition path focused on listening and spoken language via the use of assistive technologies like hearing aids and cochlear implants, and are even sometimes told to abdicate the use of any signed language (see, e.g. Humphries et al., 2012, Humphries et al., 2016, Mauldin, 2012).

The recommendations that parents of deaf children choose solely spoken language acquisition paths rather than opting for bilingual-bimodal language acquisition (that is, spoken *and* signed language) have been driven by a variety of factors. Mauldin (2016) argues that the medicalized view of deafness as a 'condition to be fixed' often influences clinical/professional recommendations made to parents (i.e. so that a deaf child can grow up like 'typical' hearing children, learning spoken language). These recommendations are fueled, additionally, by misunderstandings of how language acquisition and neural plasticity work, and by poorly designed research with deaf and hard of hearing children with cochlear implants that makes alarmist and unsupported claims related to the use of signed languages with this population (see Hall et al., 2019, for a thorough rebuttal to one such study).

However, even with assistive devices like hearing aids and cochlear implants, most deaf and hard of hearing individuals do not have typical hearing levels. As a result, deaf and hard of hearing children likely have less access to language than do typically hearing children; for example, Caldwell & Nittrouer (2013) found that 5-year-old deaf and hard of hearing children with cochlear implants, despite having undergone significant speech therapy and having used their devices for at

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least three years, had poorer speech recognition and phonological awareness than same-aged typically hearing peers. Poorer access to the sound signal is highly likely to have negative consequences for spoken language learning—indeed, in the same study, the authors also found that children with cochlear implants had poorer receptive and expressive vocabularies than typically hearing children.

A large body of work has attempted to measure vocabulary development in deaf and hard of hearing children with cochlear implants, with the hope of identifying potential environmental or individual characteristics that predict or encourage age-typical vocabulary development (see Lund, 2016, for a review of this literature). However, findings from this literature are often contradictory, and sometimes lack validity, generalizability, or practical applicability due to the use of methodologies that are missing key elements, or are inappropriate for the populations under study. Lund (2016) identifies several of the methodological limitations of previous studies in this literature, including the following: difficulties using norm-referencing; problems with comparing vocabulary assessments of different types (e.g., expressive vs. receptive); and the importance of considering the effects of variability in child-level characteristics on study outcomes.

Lund first notes that many studies compare deaf and hard of hearing children's vocabulary scores on a particular assessment to existing age-referenced norms, rather than making direct comparisons to the vocabulary scores of a matched group of typically hearing children. Norms are only applicable to a population with specific characteristics if they are generated based on a large enough sample of that population. For instance, it would most likely be inappropriate to apply norms generated with a population of American male-identifying seniors to female-identifying teenagers from India. Deaf and hard of hearing children with cochlear implants are a *highly* variable group and they represent a very small proportion of the population of children at large, so finding a "large enough" norming population is a difficult prospect at best (see Prezbindowski & Lederberg, 2003; Henner, Hoffmeister, & Reis, 2017; Henner, Reis, & Hoffmeister, 2018; and Henner, Novogrodsky, et al., 2018, for further discussion). Since very few (if any) spoken English vocabulary assessments have been specifically normed with a large enough population of deaf and hard of hearing children with cochlear implants, it is inappropriate to apply existing norms to these populations with the goal of determining whether the task performance of deaf and hard of hearing children with cochlear implants is "age-typical".

Instead of using norm-referencing, Lund recommends that researchers employ direct comparisons of deaf and hard of hearing and typically hearing children, matched on various demographic characteristics. Doing so also resolves the third issue Lund identifies: namely, that various child-level characteristics like age or family socioeconomic status (SES) can affect performance on a task. There is ample evidence indicating that family SES affects children's language development (see, e.g., Lopez Boo, 2016, Reynolds et al., 2017, Fernald et al., 2013). Lund (2016) describes the findings of a study by Qi and colleagues (2006) in which SES significantly affected not only children's actual performance on vocabulary assessments, but the characteristics of the distribution of vocabulary scores for children in specific SES brackets. In particular, scores for groups of children in a lower SES bracket resulted in distributions that were still normal, but the distribution was shifted such that mean scores for children in that group were about 1.5 standard deviations lower relative to the entire norming sample.

In a meta-analysis of 16 studies that compared vocabulary knowledge of deaf and hard of hearing children with cochlear implants to that of a matched group of typically hearing children, Lund (2016) found that children with cochlear implants had lower vocabulary scores than typically hearing children. Furthermore, the age at which children received their implants, the duration of implantation, and their age at testing did not significantly relate to the size of the effect. In the present study, we aim to add to the body of work Lund evaluates by comparing the receptive vocabulary scores—using the Peabody Picture-Vocabulary Test (PPVT; Dunn & Dunn, 2007)—of typically hearing children and deaf and hard of hearing children who are acquiring spoken English using assistive technologies (e.g., hearing aids and cochlear implants). This will help further elucidate the effects of delayed and degraded access to spoken language on children's receptive vocabulary.

Three of the studies included in Lund's (2016) meta-analysis compared receptive vocabulary of deaf and hard of hearing children with cochlear implants within the age range we include in our study to that of age-matched typically hearing children, using the PPVT (either the PPVT-III or the PPVT-IV; Ambrose et al., 2013; Walker & McGregor, 2012; Luckhurst et al., 2013). However, all three studies used standardized PPVT scores, which is problematic with this population for the same reasons that norm-referencing is inappropriate (discussed above). The technical specifications of the PPVT-4 discuss characteristics of the norming sample--overall, the sample included about 3500 individuals aged 2-90 (Pearson, 2007). A later section in the same document states the norming sample includes 99 deaf and hard of hearing children, between the ages of 4 and 12 years. The PPVT norming information included no information regarding what language(s) the deaf and hard of hearing children were learning, or at what point in development their access to any language(s) began. The fact that the PPVT norming sample did include deaf and hard of hearing children may seem to resolve the issues with norm-referencing for this test, but it is important to consider that estimates of the incidence of hearing loss in children vary depending on the age range in question, and that this group is highly heterogeneous.

The National Institute on Deafness and Other Communication Disorders (NIDCD, 2010) reports that 0.2-0.3% of babies born between 1997 and 2007 had hearing loss, and a study summarizing results from the Third National Health and Nutrition Examination Survey, conducted between 1988 and 1994, found that approximately 15% of children aged 6-19 years had hearing loss (Niskar et al., 1998). The true proportion of deaf and hard of hearing children between 1 and 18 years of age likely lies somewhere between these two values. More importantly, there is extremely high variability within the deaf and hard of hearing population in terms of degree of hearing loss, onset of hearing loss, early language exposure/experiences, use of assistive technologies, and access to language support/therapy. For this reason, *the PPVT norming sample for deaf and hard of hearing children is likely not sufficiently representative of the populatio*n. Consequently, standardized PPVT scores are inappropriate for use with deaf and hard of hearing children (Prezbindowski & Lederberg, 2003; Henner, Hoffmeister, & Reis, 2018). Here we use PPVT raw scores, which provide a more appropriate measure of receptive vocabulary that can be compared across deaf and hard of hearing and typically hearing groups (see "Coding" section for information on how this is calculated).

2. Methods

2.1. Participants

We tested two groups of children who were acquiring spoken English. Their ages ranged from 2;11-6;8 (years; months -- see Table 1 for more demographic information). These groups of children differed in the timing of their exposure to language. Children in the **English Early** group were typically hearing, and received spoken English input from birth. Children in the **English Later** group were deaf or hard of hearing and acquiring spoken English via assistive listening technology. Although it is difficult to say exactly when children in this group were *first* exposed to spoken English, we measured age of exposure to language as the age at which they received their first assistive listening device (e.g., hearing aids or cochlear implants).

For children who had hearing loss in one ear only, or who were characterized as hard of hearing on the background questionnaire that parents completed, we assumed the age at which children were exposed to *some* spoken language to be zero (i.e., from birth). We recognize that, whether we are looking at children who are profoundly deaf from birth, or children who are born hearing who became deaf as a result of an early childhood illness, this measure of first access to language is imperfect. More important than the age at which a child was first exposed to spoken language is how much cumulative access to spoken language the child has had, as well as the quantity and quality of that input (see, for example, Hall, 2017). This turns out to be extremely difficult to estimate or calculate, as it depends on the onset of children's deafness, severity of deafness, residual (unaided) hearing levels, assistive technology history and current use, and aided hearing levels, as well as parent characteristics. We place less weight on attempting to determine the precise age of first exposure to language, or cumulative amount of access to spoken language, because, by definition, all children in the deaf and hard of hearing category are missing out on *some* degree of language access.

Table 1. Participant demographic information

Group	Mean Age (range)	Median Socioeconomic Status (range)	Language Experience
English Early (*n*=47) Typically hearing children	4;8 (3;0 - 6;6)	54.5 (20 - 66)	Exposed to language from birth
English Later (*n*=28) Deaf and hard of hearing children	5;0 3;3 - 6;7)	51.75 (3 - 66)	Mean age of language exposure: ~23 months

2.2. Materials and Procedure

The PPVT stimulus book comprises drawn depictions of various actions and objects (e.g., a man walking a dog, a child sleeping, or a balloon). The target vocabulary item and foil images become more complex as the test progresses, and include, for example, human anatomy and different architectural styles. A 13-inch MacBook Pro laptop was used to deliver a slideshow of spoken English target vocabulary items.[1] The slideshow contained a native English speaker saying each of the targeted vocabulary terms. On all items, the individual producing the vocabulary terms stood in front of a light grey background.

The experimenter sat beside the child, with the PPVT booklet and laptop set up in front of the child (see Figure 1 for a picture of the experimental setup). The experimenter explained to the child that they would be shown a series of videos of a woman saying a word, and that, after each one, they must point to the picture that best matched the given word. Following the standard procedure, the experimenter determined the starting set for the child based on the child's age. If a child had more than one error in their starting set, the experimenter tested the previous set. This was continued until a basal set (i.e., a set in which a child had one or no errors) was found. Once the child completed the basal set, the experimenter continued through subsequent sets until a child provided 8 wrong answers within the set of 12.

[1] We changed the presentation of the words from the standard PPVT procedure for methodological reasons. This study is drawn from a larger study that examines the effects of both the timing of language experience (as in the current study) as well as the modality of language, that is, whether children are acquiring a signed or spoken language. Thus, we adapted the PPVT into American Sign Language (ASL); in order for both the English and ASL stimuli to have comparable visual components, we chose to present videos of the spoken English words. Furthermore, for the deaf and hard of hearing participants acquiring spoken English, using the same video-recorded presentation of spoken words for all participants removes potential variability introduced by having different experimenters (with different voice pitch, tone, pronunciation, and facial movements) produce the vocabulary words live with different participants.

When presenting the vocabulary items, if the child appeared confused or did not respond, the experimenter could replay the videos as many times as necessary. If the child continued to not respond, the experimenter asked the child to 'provide their best guess.' Once the child selected an item, the experimenter moved on to the next item in the PPVT booklet. If the child appeared to be responding too quickly and not paying attention to the items, the experimenter would tell the child to take their time and examine all four picture choices before selecting. The child's responses were video-recorded and coded offline.

Native English speakers coded all videos. Correct responses were coded with "1," and incorrect answers were coded with "0". The coder recorded the start set, the start item, and the last item completed. Based on the child's performance, the experimenter noted the basal set, the ceiling set, and calculated the child's raw score based on instructions in the PPVT manual.

Figure 1. Experimental setup for PPVT. A deaf child acquiring spoken English, age 4;2, pointing to the picture in the stimulus book she believes matches the vocabulary word presented on the laptop.

3. Results

We used a linear regression to ask whether the timing of children's language exposure (Language Timing: Early vs. Later) significantly predicted PPVT raw scores, controlling for the child's age and family's socioeconomic status (SES, Barratt, 2006). We predicted that children with delayed exposure to English would score lower than children with early exposure. We also asked whether the rate of vocabulary development (approximated by our cross-sectional age sample) differed for Early- versus Later-exposed children.

Figure 2 presents a scatterplot of the data from each child. The linear model showed that Age contributed significantly to the variability in PPVT raw scores; children improved by ~18 points per year of age. There was also a significant effect of Language Timing, controlling for Age and Socioeconomic status. Hearing children exposed to English early had better scores (by ~11.5 points) than deaf and hard of hearing children exposed to English later. An added interaction term between Age and Language Timing was not significant, and did not improve model fit, suggesting approximately similar rates of acquisition for deaf and hard of hearing and hearing children (see fit lines in Figure 2). Figure 3 shows different plots of the model's residuals; the distributions of points in these plots confirm that a linear model is a good fit for these data.

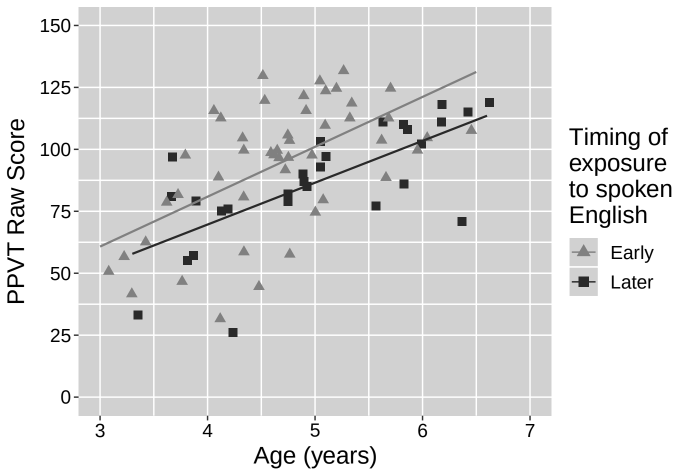

Figure 2. Scatterplot showing PPVT Raw score by Age for typically hearing children (English Early, gray triangles) and Deaf/Hard of Hearing children (English Later, black squares).

Table 2. Linear Regression Results

	Dependent variable:
	PPVT Raw Score
Socioeconomic Status (SES)	0.230 (0.174)
Age (Years)	18.027^{**} (2.836)
Language Timing (Later)	-11.539^{*} (5.045)
Constant	-2.545 (15.890)
Observations	73
R^2	0.408
Adjusted R^2	0.382
Residual Std. Error	19.670 (df = 69)
F Statistic	15.852^{**} (df = 3; 69)
Note:	$^{*}p<.05$, $^{**}p<0.01$

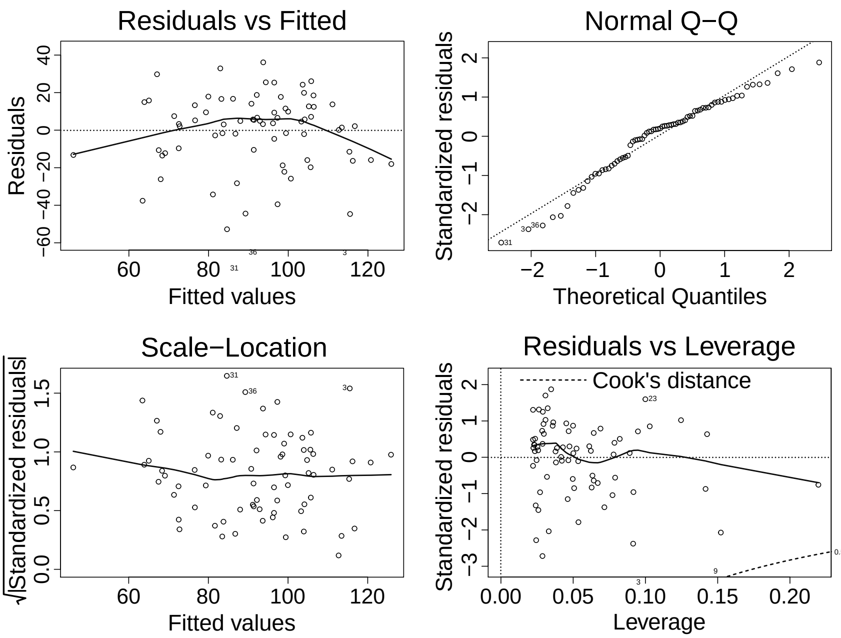

Figure 3. Residual plots for the model in Table 2 show that linear model used is a good fit for the data.

4. Discussion

Our findings indicate that the language acquisition capabilities of deaf and hard of hearing children are likely equivalent to those of hearing children. However, longitudinal data (rather than our cross-sectional sample) are needed to definitively confirm that deaf and hard of hearing children acquire vocabulary at the same rate as typically hearing peers. One other study that used PPVT raw scores to examine the effects of age of implantation on receptive vocabulary found, unsurprisingly, that children who received cochlear implants earlier (i.e., before 2.5 years of age) performed better and improved more rapidly than those who received cochlear implants later (Connor et al., 2006). However, Connor et al. (2006) did not include a typically hearing control group, and so also could not address whether earlier CI implantation leads to comparable receptive vocabulary outcomes or acquisition rates as those observed for same-aged typically hearing children.

The critical finding in the present work is that despite similar rates of acquisition, at *all ages examined in our study, there is a gap in receptive vocabulary between deaf and hard of hearing children and same-aged typically hearing children*. Even with the best technology currently available and the earliest possible or practical implantation, deaf and hard of hearing children acquiring spoken language almost assuredly do not have access to an important amount of spoken language input. Our data elucidate the consequences of this degraded or incomplete input: deaf and hard of hearing children with cochlear implants and hearing aids had significantly lower receptive vocabulary scores than typically hearing children of the same age. The implication of this finding is critical for parents, researchers, and clinicians to be aware of: *cochlear implants and other hearing technology* do not guarantee *that all deaf and hard of hearing children who use these technologies will develop age-typical receptive vocabulary skills.*

This is particularly important in light of Lund's (2016) meta-analysis findings that some oft-touted predictors of children's success with assistive technologies (e.g. earlier age of implantation) did not make children with cochlear implants more likely to be equivalent to or "catch up" to the vocabulary scores achieved by their typically hearing peers. Although other studies have found benefits of earlier rather than later implantation in deaf and hard of hearing children with cochlear implants for certain outcomes, when validated assessments are used (and used correctly), and appropriate comparison groups included, this benefit disappears (Lund, 2016). We therefore remain without solid evidence regarding what factors truly allow deaf and hard of hearing children with assistive technologies to acquire spoken language on a timetable similar to their typically hearing peers. Meanwhile, a growing literature demonstrates cascading, negative consequences for development when deaf and hard of hearing children who use assistive technologies to acquire spoken language have smaller vocabularies. These consequences apply both within the domain of language acquisition, as well as in other developmental domains.

For instance, not having age-typical vocabulary skills may actually make word learning more difficult. Walker & McGregor (2012) found that deaf and hard of hearing children with cochlear implants did not demonstrate evidence of using word-learning principles like fast-mapping, extension, and retention to the same degree that their age-matched typically hearing peers did. In fact, deaf and hard of hearing children's word-learning abilities more closely resembled those of vocabulary-matched typically hearing children who were on average a full year younger. Numerous other studies discuss the cognitive, emotional, psychological, social, and educational consequences of early language deprivation (e.g., Humphries et al., 2012; Hall et al., 2017, Henner et al., 2016; Gagne & Coppola, 2017; Hauser et al., 2008; Martin et al., 2013; Marshall et al., 2015; Carrigan et al., in prep). Szarkowski (2018) summarizes the challenges faced by deaf and hard of hearing children with cochlear implants and makes suggestions for professionals regarding best practices for fostering their linguistic competence. We particularly encourage our audience to read Humphries et al. (2014a) for a review of some of this research, and for a detailed list of recommendations for *what linguists can do to help promote adequate language access for deaf and hard of hearing children* (with or without assistive technologies).

If spoken-language-only approaches are insufficient for deaf and hard of hearing children to develop on par with their typically hearing peers, other options must be seriously considered. Indeed, the primary recommendation in Humphries et al. (2014a) is that *all* deaf and hard of hearing children receive exposure to sign language as soon as hearing loss is identified. A growing body of literature suggests that early exposure to sign language bolsters development across the board for deaf and hard of hearing children. Deaf and hard of hearing children with early sign exposure (regardless of what language they are focusing on producing or assistive technologies they use) have cognitive abilities on par with typically hearing peers (e.g., Hall et al., 2018; Dostal & Wolbers, 2014). Deaf and hard of hearing children with cochlear implants who have early access to sign language outperform deaf and hard of hearing children with cochlear implants who are not exposed to signed language on speech and language assessments (Hassanzadeh, 2012). Finally, deaf and hard of hearing children with cochlear implants exposed to signed language early in life perform equally well on spoken language assessments as same-aged typically hearing bimodal-bilingual peers (Davidson et al., 2014).

Our work adds to this body of evidence supporting the recommendation that even when parents wish for their deaf and hard of hearing child to acquire spoken language, *access to sign language should be provided to bridge any language acquisition gaps resulting from incomplete access to spoken language.* In addition to the importance of scientists acknowledging and further studying how early access to signed language improves outcomes for deaf and hard of hearing children, it is also critical to consider how to make clinicians, educators, and parents aware of these findings, and how to help these groups support richer accessible language environments for deaf and hard of hearing children. Below we discuss some of the efforts that must be made with each of these groups.

In the journal *Medical Science Educator*, Humphries and colleagues (2014b) describe what upcoming generations of medical professionals must learn in order to accurately and sensitively engage with parents on this topic. They advocate ensuring that medical education curricula include ample current and well-validated information on language acquisition in deaf and hard of hearing children and the potential dangers of spoken-language-only approaches. It is also extremely important that medical professionals be able to answer commonly-asked questions from families learning about language development in their deaf and hard of hearing child, and can provide families with easy-to-access resources about acquiring signed languages. Humphries et al. (2015) provide a list of such questions, and outline detailed, evidence-based responses and resources that clinicians can pass on to parents.

Educational programs and resources for teachers of the deaf must also be modified to include up-to-date information on the potential benefits of increased exposure to natural signed language for deaf and hard of hearing children. Although many such training programs and materials currently exists, the field of deaf education is currently weighted in favor of approaches emphasizing listening and spoken language, or other communication methods that lack solid empirical validity (e.g. Signed Exact English, Scott & Henner, under review). The Laurent Clerc National Deaf Education Center has compiled and organized a variety of excellent evidence-based resources for deaf educators as well as parents of deaf children (Clerc Center, 2015). However, these resources are currently available as piecemeal offerings for interested parties, rather than incorporated into curricula for teachers of the deaf in various programs.

Finally, it is critical that we provide parents with resources to learn about signed languages and the benefits they can provide not just to deaf and hard of hearing children, but to families as a whole (Kushalnagar et al., 2007; Leigh, 2008). Some parents are fortunate enough to either encounter or intuit these benefits and make the choice to learn and incorporate signed language into their lives and communicative practices with their deaf child (e.g. Chen Pichler, 2019). Furthermore, parents should be advised to seek educational options for their child that maintain a rich, accessible language environment (i.e., educational programs that use signed language in addition to the spoken and written language of the community). Henner et al. (2016) found that the age at which children enter a signing program (namely a school for the deaf) significantly predicts their language-based analogical reasoning, regardless of whether their parents are deaf signers or hearing non-signers. We must continue to work on identifying barriers faced by parents in attempting to provide access to signed language to their deaf and hard of hearing child (e.g., lack of available local resources--funding, personnel, and programs) in order to remedy these barriers, so that deaf and hard of hearing children have the best chances of achieving optimal developmental outcomes.

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