The Influence of Early Sensory and Linguistic Experience on Lexical Development

by

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Dissertation submitted in partial fulfillment of
the requirements for the degree of Doctor of Philosophy
in the Department of Psychology & Neuroscience
in the Graduate School
of Duke University

2023

ABSTRACT

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Abstract

Across four studies, we aim to understand how differential access to perceptual and linguistic information impacts early lexical development. To get traction on this question, we study the early word productions and language environment of young children born deaf or blind. In Chapter 1, we explore why differences in perception and language would influence the developing lexicon. In Chapter 2, we use clinical reports from state early intervention services for Deaf/Hard-of-Hearing (DHH) children to characterize the demographic, audiological, and intervention variability among this population, and identify predictors delays in vocabulary, diagnosis, and intervention. Chapter 3 turns to blind children and provides an in-depth look at the size and composition of early vocabulary, offering insight into how vision influences lexical development. In Chapter 4, we leverage vocabulary data from English-speaking congenitally-blind toddlers and deaf toddlers, relative to their typically-sighted/hearing peers, as well as two sets of deaf children learning American Sign Language. With this unique dataset, we explore how perceptual and linguistic access influence production of words with referents that children cannot physically perceive. Chapter 5 asks whether language *input* is affected by sensory impairment, with implications for how blind children may utilize the language input to build linguistic knowledge. Summarizing across these studies, we find that both blindness and deafness are associated with spoken vocabulary delays, although the mechanisms likely differ. We find that the magnitude of these delays is sensitive to characteristics of the exact diagnosis, highlighting the need for improved rates of early diagnosis and intervention for particular subsets of these populations. While the composition of vocabulary seems largely resilient to differences in perceptual experience, we find that children are selectively less likely to produce words that are highly and exclusively associated with the impaired modality. Lastly, we find that children's language environments may differ as a function of their sensory abilities: blind children's language environments contain longer utterances and less "here-and-now" talk. In conclusion, We show here the resilience of language development to various learning conditions and highlight the importance of language input in providing rich information in the absence of direct perceptual experience. These studies contribute valuable insights into language development in children with sensory impairments but also language development more broadly.

Dedication

To my incredible parents.

To my Mom, who has devoted her life to nurturing young children, including me. Thank you for being my first teacher, a great friend, and a participant / co-conspirator in our unpublished 2012 language acquisition case study: *Exploring the Feasibility of Acquiring Elementary German Language Skills through CD-Based Learning during a Round Trip Car Ride to Harrisonburg, Virginia*. You're a vibrant and vital part of die Farben meines Lebens. Thank you also for your frequent early-life encouragement for me to "use [my] words." I did! 45,000 of them.

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I dedicate this dissertation to you with love and pride.

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1. Introduction

Infants navigate a complex landscape of sounds, smells, and colors, initially faced with a seemingly bewildering array of inputs. However, infants also possess a remarkable ability to discern meaning. By only 6 months of age, infants begin to form links between word labels and frequent objects or events in their environment (Bergelson & Swingley, 2012). Infants' perceptual, cognitive, and linguistic skills improve in tandem over the first years of life. For instance, as infants' visual acuity develops, they demonstrate improved gaze following (Zohary et al., 2022). As children begin babbling and later talking, they are involved in increasingly complex social interactions (Dailey & Bergelson, 2023). Through this combination of perceptual input, linguistic input, and cognitive mechanisms, infants quickly build up knowledge about the world around them.

The individual contributions of language, perception, and cognition to learning are challenging to disentangle. Do each of these develop independently, or is perception, instead, a necessary foundation and critical contributor to language and cognitive development? Individuals with perceptual differences provide us with a unique way to begin to disentangle these contributions. We can observe the effects of *absence* of visual or auditory perception on the development of language and cognition, thus gaining insight into the broader question of how humans learn by integrating information from multiple sources.

Traditional theories of word learning (Byers-Heinlein et al., 2013; Golinkoff & Hirsh-Pasek, 2006; Hirsh-Pasek Kathy, 1999; Piaget, 1952; Pruden et al., 2006; Smith, 2000; Unger et al., 2020; Vygotsky, 1978; Werker et al., 1998) suggest that children learn words through the repeated co-occurrence of perceptual events (seeing a ball) and word labels (hearing "that's a ball!"). Children also have some cognitive tools under their belt, but the two key ingredients for learning a word (at least in the earliest stages of language learning) are purported to be sensory experience and linguistic experience (Dollaghan, 1985; Golinkoff et al., 1994; Yu & Smith, 2007). This explanation, however, does not adequately explain vocabulary acquisition for all learners. In the United States, approximately 2-3/1000 children are born deaf (CDC, 2019), and 1/10000 children are born blind (Gilbert & Awan, 2003). Does access to sight or sound affect how children learn language or learn information through language, and if so, by what mechanism? By studying children with congenital sensory impairments, we can better understand the flexibility and limits of the language learning process.

We focus here on lexical development, the process of acquiring a vocabulary. This facet of language development represents the coming together of multiple components of linguistic knowledge: most saliently, phonological and semantic knowledge, which, as we will discuss below, may be particularly relevant for children with sensory impairments. Moreover, the development of the lexicon can tell us whether sensory experience (auditory or visual) and linguistic experience are both necessary components for building a vocabulary. If one of these inputs is absent, how does lexical development proceed? If visual or auditory input is important for word learning, then we should expect to find differences in lexical development among congenitally deaf or blind children (respectively). Likewise, if language input is important, then when language access is delayed or reduced (as is the case for deaf children born into spoken language households), we should expect to find vocabulary delays. The following sections discuss each of these factors further.

1.1 Language Input and Language Development

Put simply, when young children are denied access to language, they do not learn language (Curtiss et al., 1974; Ferjan Ramírez et al., 2013; Kegl, 2018). Studies of language deprivation (wherein children do not receive access to language input for the first years of their life) show us that lack of access to language in early childhood leads to persistent differences in executive function (Hall et al., 2017), neural structure (Mayberry et al., 2011; Pénicaud et al., 2013; Skotara et al., 2012; Vyshedskiy et al., 2017; Wang et al., 2022), morphosyntax (Boudreault & Mayberry, 2006; Mayberry, 1993; Vyshedskiy et al., 2017), and the adult lexicon (Caselli, 2015).

Even outside of these more extreme cases, among both typically-developing children and children with developmental differences, language input is an important predictor of language outcomes (Anderson et al., 2021; Gilkerson et al., 2018; Huttenlocher et al., 1991, 2010; Rowe, 2012, 2013), with more language exposure generally linked with larger vocabulary (Anderson et al., 2021; Gilkerson et al., 2018; Huttenlocher et al., 1991; Rowe, 2008). Qualitative aspects of the language input also seem to matter: parent responsiveness, amount of child-directed (vs. overheard) speech, conversational turn-taking, lexical diversity, and grammatical complexity have each been implicated in language outcomes (Anderson et al., 2021; De Villiers, 1985; Donnellan et al., 2020; Goldstein & Schwade, 2008; Hadley et al., 2017; Hirsh-Pasek et al., 2015; Hoff, 2003; Hsu et al., 2017; Huttenlocher et al., 2002, 2010; Naigles & Hoff-Ginsberg, 1998; Newman et al., 2016; Romeo et al., 2018; Rowe, 2012, 2013; Shneidman et al., 2013; Weisleder & Fernald, 2013; Weizman & Snow, 2001).

Language also serves an additional role in learning in other domains. For all individuals, regardless of perceptual abilities, language affords access to things we cannot directly experience. A friend can tell us about a meeting we missed. Through reading, we can learn about newly-discovered aquatic species, without having to visit the deep sea ourselves. In the absence of direct perceptual experience, language can provide information about the world. It follows, by hypothesis, that the role of language as a medium for acquiring world knowledge is greater for individuals with sensory impairments (Campbell & Bergelson, 2022b). It remains unclear, however, whether language input and perceptual experience are independent from one another; the language input could differ for children with sensory impairments relative to their typically-sighted/hearing peers.

1.2 Auditory Input and Language Development

Spoken language development hinges on temporally and acoustically precise auditory perception. For instance, in English, differentiating between the sounds /t/ and

/d/ involves detecting a difference of 1/10th of a second in the onset of vibration of the speaker's vocal cords (Lisker & Abramson, 1964). Yet, infants as young as 1 month old are already sensitive to these subtle timing differences (Eimas et al., 1971). Likewise, even newborn infants perceive distinctions in prosody (Christophe et al., 2001; Martinez-Alvarez et al., 2023) and notice changes in rhythm and pitch across utterances. These auditory skills help children parse out word boundaries and detect lexically important sound changes (Johnson et al., 2014; Werker & Tees, 1984). In fact, children begin to accrue linguistic knowledge through hearing even in the womb: newborns can distinguish their mothers' voices from other women's voices (DeCasper & Fifer, 1980) and their native language from other languages (Hym et al., 2023). Over time, as children continue to accumulate language experience (through hearing, for spoken language), they learn the sounds, words, and structure of their native language.

1.2.1 Deafness

However, not all infants have access to language input in utero, or even through toddlerhood. Approximately 90% of deaf children are born to hearing parents (Mitchell & Karchmer, 2004), into households where the primary language is a spoken language (Mitchell & Karchmer, 2005). This results in a communicative mismatch, wherein the parents' primary language is perceptually inaccessible to the child. As a result, many deaf children, even those with minimal hearing loss (Blair et al., 1985; Winiger et al., 2016), show highly variable language outcomes (Pisoni et al., 2018) and commonly have spoken vocabulary delays (Eisenberg, 2007; Luckner & Cooke, 2010; Moeller et al., 2007).

To restore partial access to sound, some parents choose to get hearing aids or cochlear implants for their deaf children, but even then, outcomes remain variable (Niparko et al., 2010; Pisoni et al., 2018), with many children lagging behind their typically-hearing peers in language and literacy. More severe hearing loss tends to be associated with greater delays in spoken language (Ching et al., 2013; de Diego-Lázaro et al., 2018; Vohr et al., 2011; Yoshinaga-Itano et al., 2017), further underscoring the important role of auditory access in acquiring spoken language in particular. On the flip side, deaf children who receive early access to language through a sign language, which they can access easily through vision, achieve age-appropriate language milestones (Caselli et al., 2021; Petitto & Marentette, 1991). This indicates that deafness does not impede language acquisition broadly, but rather delays are specific to the auditory modality.

1.3 Visual Input and Language Development

The function of vision in spoken language development differs from the role of audition, but visual input can supply young language-learners with several advantages and cues. Through vision, children can receive clues to word meaning, at least for words that involve mapping to a tangible entity in the world. This includes social cues, like pointing or eye gaze, which can lend insight into a speaker’s communicative intent (Brooks & Meltzoff, 2008; Carpenter et al., 1998; Meltzoff & Brooks, 2009; Moore et al., 2019). Vision also provides sensorimotor cues, like the visual salience of an object, or access to the object of a speaker’s gaze or point.

While these cues can, in theory, be perceived through other modalities, non-visual perception of these cues tends to develop later (if at all) in the course of typical development. For instance, while infants will reach towards objects in their visual field at 4–6 months, auditory-directed reaching (ex: towards a toy making noise) does not emerge until around 8 months. Additionally, the set of things within infants' reach is limited compared to the set of things within infants' visual field. Therefore, some referents that are perceptible through sight (e.g., clouds, a toy on the other side of the room) are imperceptible through touch.

1.3.1 Blind Children

Like deaf children, the vast majority of blind children are born into spoken language households, but unlike deaf children, spoken language is immediately accessible for blind children, while, referential cues such as pointing, eye gaze, or visual saliency, are not. It remains unclear whether and how this affects language development. Because congenital blindness is so rare (1/10000), studies of language development in this population are limited in sample size, typically ranging from 2-10 participants (e.g., Bigelow, 1990; Landau & Gleitman, 1985). Interpretation of prior research is further complicated by the fact that many children with early blindness are often born extremely premature (i.e., Seiberth & Linderkamp, 2000) or with cognitive or developmental comorbidities (Borchert & Garcia-Filion, 2008; Malkowicz et al., 2006). Additionally, these early studies yield conflicting results: some studies find early vocabulary delays in blind individuals (Bigelow, 1990; Mulford, 1988; Nelson, 1973), while others report age-appropriate vocabulary (Landau & Gleitman, 1985; Mcconachie & Moore, 1994). This makes the question of whether access to vision affects the course of language development difficult to resolve.

1.4 The Present Work

Children learn about the world through direct experience and through language. However, language and perception are not equivalent sources of information and are not equally available to all children. Blind and deaf infants therefore likely have fewer perceptually accessible instances from which to acquire world knowledge, word-world mappings, and language structure; this is compounded further when full language access is not available (e.g., for deaf children without sign language input). The acquisition of language and world knowledge in children is fundamentally influenced by their access to perceptual information and linguistic input, making it crucial to explore the consequences when one or both of these sources are limited. This dissertation asks specifically: how do you build a lexicon when access to one or both of these information sources is limited, and how is the lexicon linked to other facets of learning?

Each of the following chapters focuses on how language input and perception interact in young children's experiences and how these experiences may shape the lexicon. Chapter 2 (Campbell & Bergelson, 2022a) explores the demographic, audiological, and intervention variability in Deaf/Hard-of-Hearing children receiving early intervention services, and identifies factors that predict delays in vocabulary development. By examining the factors that influence vocabulary outcomes and early intervention efforts in a diverse sample of Deaf/Hard-of-Hearing children, this chapter sheds light on the complexities of developing a lexicon in the absence of typical auditory input. Chapter 3 (Campbell et al., submitted) investigates the extent to which vision influences early word production by studying the vocabulary development of congenitally blind children. Here, we measure how access to visual input influences the growth and composition of children's vocabularies. In Chapter 4 (Campbell, Davis, Cooke, Houston, Caselli, & Bergelson, *under review*), we study both populations, deaf children and blind children, and measure the production of words with referents that can be perceived against words with imperceptible referents. In this study, we analyze how direct sensory access to sight and sound, as well as early or late access to language, shape the words that enter children's early vocabulary. Chapter 5 delves into a comparative study of language input to young blind children and their sighted peers in naturalistic home settings. Using LENA audio recorders, the study analyzes quantitative, interactive, linguistic, and conceptual features of language input to determine whether there are any significant differences between the two groups. By comparing language input in naturalistic home settings, the study offers valuable insights into potential disparities in language exposure for young blind children and their sighted peers, enriching our understanding of language input in diverse contexts.

These studies seek to unravel the implications of differences in perceptual and linguistic input on children's lexical acquisition. Across these chapters, we explore the intricate interplay between perception, cognition, and input in early language development.

2. Characterizing North Carolina's Deaf/Hard-of-Hearing Infants and Toddlers: Predictors of Vocabulary, Diagnosis, and Intervention

2.1 Introduction

In the United States, 1-2 children are born with hearing loss, per 1,000 births , of which ~90% will be born to hearing parents (Mitchell & Karchmer, 2004), in a home where spoken language is likely the dominant communication method. Depending on the type and degree of hearing loss, whether the child uses amplification, and whether there is any access to sign language, linguistic input may be partially or totally inaccessible. Despite growing, converging evidence for benefits of early sign language exposure (e.g., Clark et al., 2016; Davidson et al., 2014; Hrastinski & Wilbur, 2016; Magnuson, 2000; Schick et al., 2007; Spencer, 1993), the majority of U.S. DHH children (and particularly those in our North Carolina-based sample) are not raised in a sign language environment. While some of these children will develop spoken language proficiency within the range of their hearing peers (Geers et al., 2017; Verhaert et al., 2008), many will face persistent language deficits (Eisenberg, 2007; Luckner & Cooke, 2010; Moeller et al., 2007), which may later affect reading ability and academic achievement (Karchmer & Mitchell, 2003; Qi & Mitchell, 2012). Given this, we focus primarily on spoken language development.

Though the literature points towards spoken language delays and deficits for Deaf or Hard-of-Hearing (DHH) children, this is a highly variable population with highly variable language outcomes (Pisoni et al., 2018). For instance, previous research indicates that gender (Ching et al., 2013; Kiese-Himmel & Ohlwein, 2002), additional disability (Ching et al., 2013; Verhaert et al., 2008; Vohr et al., 2011; Yoshinaga-Itano et al., 2017, 2018), degree and configuration of hearing loss (Ching et al., 2013; de Diego-Lázaro et al., 2018; Vohr et al., 2011; Yoshinaga-Itano et al., 2017), amplification (Walker et al., 2015), communication (Geers et al., 2017), and early diagnosis/intervention (Yoshinaga-Itano et al., 2017, 2018) influence language outcomes in DHH children. Although many of these variables reflect immutable characteristics of the child, such as comorbid diagnoses or configuration of hearing loss, some represent opportunities for clinicians and policy makers to intervene and potentially improve language outcomes for DHH children.

More specifically, early identification (Apuzzo & Yoshinaga-Itano, 1995; Kennedy et al., 2006; Robinshaw, 1995; White & White, 1987; Yoshinaga-Itano et al., 1998, 2018) and timely enrollment in early intervention programs (Ching et al., 2013; Holzinger et al., 2011; Vohr et al., 2008, 2011; Watkin et al., 2007) are associated with better language proficiency. Indeed, DHH children who receive prompt diagnosis and early access to services have been found to meet age-appropriate developmental outcomes, including language (Stika et al., 2015). In line with these findings, the American Academy of Pediatricians (AAP) has set an initiative for Early Hearing Detection and Intervention (EHDI). These EHDI guidelines recommend that DHH children are screened by 1 month old, diagnosed by 3 months, and enter early intervention services by 6 months. We refer to this guideline as 1-3-6. Meeting this standard appears to improve spoken language outcomes for children with hearing loss, and the benefits appear consistent across a range of demographic characteristics (Yoshinaga-Itano et al., 2017, 2018), so it remains an important research goal to identify children at risk of receiving clinical support late, in order to help all children achieve prompt diagnosis and intervention.

Notably, the variables linked to hearing loss mentioned above don't occur in a vacuum, yet past work has largely attempted to measure their effects as if they were independent. For instance, many studies focus on vocabulary development in specific subgroups *(e.g. children under age X with Y level of hearing loss and Z amplification approach,* e.g., Vohr et al., 2008; Yoshinaga-Itano et al., 2018*)*, which are not representative of the broader population of DHH children. We take a different tack, asking instead how these factors co-occur and interact in the context of the broad diversity of the DHH community, how they are linked to early vocabulary, and how this connects with intervention and policy guidelines, within a single state in the U.S.

2.1.1 Goals, Predictions, and Key Contributions

We present an empirical analysis of early vocabulary in a wide range of young DHH children receiving state services in North Carolina. This study aims to 1) characterize the demographic, audiological, and intervention variability in the population of DHH children receiving state services for hearing loss; 2) identify predictors of vocabulary delays; and 3) evaluate the success of early identification and intervention efforts at a state level. We include three subgroups of DHH children traditionally excluded from studies of language development: children with additional disabilities, children with unilateral hearing loss, and children from bilingual or non-English-speaking households (e.g., Yoshinaga-Itano et al., 2018).

For the first goal, we expected that many of these variables would be linked, due to known causal relations (e.g., cochlear implants recommended for severe hearing loss, but not mild hearing loss). For the second goal, we hypothesized that male (vs. female) gender, more severe degree of hearing loss, bilateral (vs. unilateral) hearing loss, no amplification (vs. hearing aids and/or cochlear implants), premature birth, not meeting 1-3-6 guidelines, and presence of additional disabilities would predict larger spoken vocabulary delay. This study builds on prior work (e.g., Ching et al., 2013; Lund, 2016; Yoshinaga-Itano et al., 2017) by taking a new modeling approach for quantifying vocabulary delay across these variables. For the third goal, we hypothesized that children with less residual hearing (i.e., bilateral, more severe) and no co-occurring conditions would be earlier diagnosed and earlier to begin language services, and that in turn earlier diagnosis would predict earlier intervention. This study helps assess compliance with EHDI guidelines, and considers pathways for improvement.

2.2 Methods

Clinical evaluations were obtained through an ongoing collaboration with the North Carolina Early Language Sensory Support Program (ELSSP), an early intervention program serving children with sensory impairments from birth to 36 months. ELSSP sent deidentified evaluations to our team after obtaining consent to do so from each family[1]. While this collaboration is ongoing, we opted to pause for this analysis upon receiving data from 100 children (collected between 2010 and 2020, before the COVID-19 epidemic reached North Carolina in Spring 2020). Given our goal of characterizing the full range of DHH children with hearing loss in North Carolina, no eligibility criteria beyond hearing loss and receiving an ELSSP evaluation were imposed.

The clinical evaluations included demographic and audiological information and MacArthur Bates Communicative Development Inventory vocabulary scores (CDI, Fenson et al., 1994). For some children, evaluations from multiple timepoints or other instruments were available (e.g. PPVT). We limit the scope of the present study to only the CDI (as this was available for all children), and only the first evaluation (due to concerns regarding within-subjects variance for statistical analysis).

The CDI is a parent-report instrument measuring children's vocabulary. On the Words and Gestures version of the form (normed for 8–18-month-olds), parents indicate whether their child understands and/or produces each of the 398 vocabulary items. On the Words and Sentences version (normed for 16–30-month-olds), parents indicate whether their child produces each of the 680 vocabulary items. Normative data for this

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[1] Because the data we received were already deidentified, this study was exempt from Duke University Institutional Review Board.

instrument (Frank et al., 2017; Jackson-Maldonado et al., 2003) is available from WordBank, an open database of CDI data. The CDI has also been validated for DHH children with cochlear implants (Thal et al., 2007) in 32–66-month-olds. We build on prior literature using the CDI to measure vocabulary in DHH children (e.g., de Diego-Lázaro et al., 2018; Vohr et al., 2008, 2011; Yoshinaga-Itano et al., 2017, 2018) with a new analytic approach below.

Table 1: Additional Diagnoses (n = 39): Ns of participants in our sample diagnosed with other conditions.

Condition	Specific Condition	n
Premature		17
	Extremely Premature	11
	NICU stay	16
Health Issues		36
	Heart	9
	Lung	5
	Illness	15
	Feeding Issues	14
	Pregnancy/Birth Complications	11
	Musculoskeletal	9
	Cleft Lip/Palate	4
	Other	15
Developmental Concerns		17
	Down Syndrome	5
	Chromosomal Issues	2
	Neural Tube Defects	2
	Other	10
Vision Loss		5
	Retinopathy of Prematurity	1
	Nearsightedness	1
	Farsightedness	1
	Cortical Visual Impairment	1

Note. Ns do not sum to total because many participants had multiple diagnoses.

Table 2: Audiological Characteristics of the Sample.

Laterality	Amplification	Degree (better ear; dB HL)	Degree (worse ear; dB HL)	Age of Amplification (months)	Age of Implantation (months)
Bilateral	CI	85.60	89.79	11.29	14.12
Bilateral	HA	47.51	56.28	8.18	*NA*
Bilateral	none	49.67	53.65	*NA*	*NA*
Unilateral	HA	4.70	54.09	9.91	*NA*
Unilateral	none	2.50	71.55	8.50	*NA*

Note. First two columns describe laterality and amplification type (cochlear implant (CI), hearing aid (HA), or none). Mean decibels of hearing loss (HL) in better ear, worse ear, and the mean age (in months) of amplification, and cochlear implantation (when applicable) for each laterality and amplification combination.

Table 3: Language and Communication Characteristics of the Sample: Ns of participants by language background and communication method.

Communication	English	Hindi	Spanish	Total
cued speech	1	0	0	1
spoken	67	1	11	79
total communication	15	0	3	18

2.3 Results

The results are organized mirroring the goals outlined above. First, we explore relationships among child demographic, audiological, and clinical variables. Second, we use these variables to predict vocabulary development. Finally, we describe the implementation of the EHDI 1-3-6 guidelines and predictors of early diagnosis and intervention in this sample. All analyses were conducted in R (R Core Team, 2020) and all code to generate this manuscript in Rstudio (RStudio Team, 2020) is available via OSF.

2.3.1 Relationships Among Demographic, Audiological, and Clinical Variables

Before testing how these variables relate to vocabulary and clinical milestones, we describe their relationships to each other. To quantify this statistically, we used Bonferroni-corrected chi-square tests between each of our variables. Because the chi-square statistic assumes $n>5$ is *expected* in the majority of the cells for each test (McHugh, 2013), we excluded mixed hearing loss ($n = 8$) and cued speech ($n = 1$) from this analysis. Strictly speaking, some variables are not expected to be randomly distributed relative to each other (e.g., premature birth and health issues; degree and amplification), but quantifying the differences via chi-square using a conservative significance threshold lets us highlight the strongest relationships within this dataset.

Of the 66 combinations of variables, $p < .05$ for 26, and 9 survived Bonferroni correction ($p < 0.0007$). We limit discussion to the latter below, but depict the full set in Figure 1.

As expected, health issues, developmental delays, and premature birth were highly interrelated in our sample, such that children born premature were more likely to also experience health issues ($\boxed{X^2}$ (1, N = 98) = 23.9, p < .0001) and developmental delays ($\boxed{X^2}$ (1, N = 98) = 13.06, p = .0003), and children with developmental delays were more likely to also experience health issues ($\boxed{X^2}$ (1, N = 98) = 18.67, p < .0001). Children with developmental delays received more services per month than typically-developing children ($\boxed{X^2}$ (2, N = 95) = 23.99, p < .0001) and were more likely to use total communication ($\boxed{X^2}$ (2, N = 98) = 24.88, p < .0001). Likewise, children who used total communication received more services per month than children using spoken language ($\boxed{X^2}$ (4, N = 95) = 21.53, p = .0002).

Table 4: Variables List: Detailed information about the variables studied.

Variable	Range
Age	4-36 months (mean (SD): 21 (9))
Age at Amplification	2-30 months (mean (SD): 9 (7))
Age at Diagnosis	0-30 months (mean (SD): 5 (7))
Age at Implantation	7-32 months (mean (SD): 14 (7))
Age at Intervention	1-33 months (mean (SD): 11 (9))
Amplification	Hearing Aid (53) / Cochlear Implant (17) / None (28)
Communication	Spoken (79) / Total Communication (18) / Cued Speech (1)
Degree Hearing Loss (worse ear)	18-100 dB HL (mean (SD): 64 (23))
Developmental Delay	Yes (16) / No (82)
Gender	Female (43) / Male (57)
Health Issues	Yes (36) / No (62)
Language in Home	English (84) / Other (16)
Laterality	Unilateral (26) / Bilateral (72)
1-3-6	Yes (34) / No (61)
Premature Birth	Full-term (16) / Premature (82)
Services Per Month	0-43 services per month (mean (SD): 5 (6))
Etiology	Sensorineural (62) / Conductive (19) / Mixed (8)
Words and Gestures CDI - Words Produced	0-259 words (mean (SD): 33 (53))
Words and Sentences CDI - Words Produced	7-635 words (mean (SD): 148 (184))

Note. For categorical variables, levels are described. Some participants had missing information for some variables, thus totals may not sum to 100. For continuous variables, range, mean, and standard deviation are provided. For CDI, participants were *either* administered Words and Gestures *or* Words and Sentences.

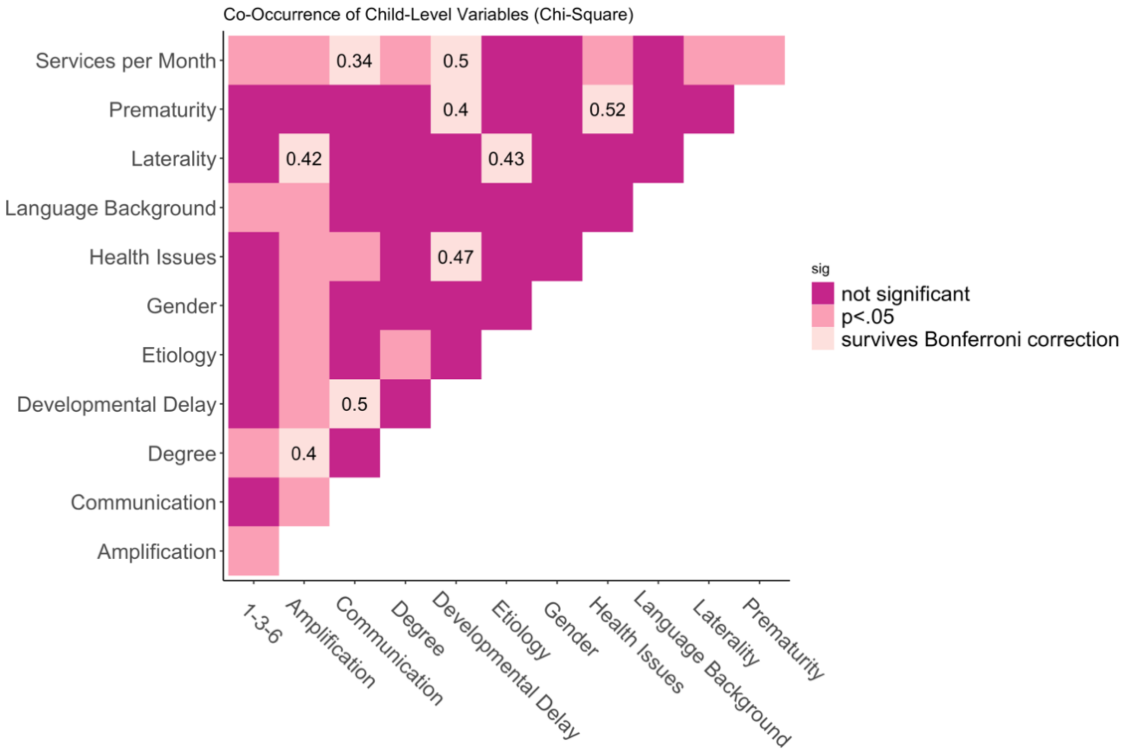

Figure 1: Results of chi-square tests between variables. X- and y-axes show the variables compared. Color of the square represents significance of the corresponding chi-square test. For tests that survived Bonferroni correction (p < .0007), effect size (Cramer's V) is given. (For the chi-square test, services received per month was binned into 0-2, 3-6, and > 7 services/month to create maximally evenly sized bins.)

We also confirmed expected relationships among many of the audiological characteristics. There was a significant relationship between laterality and etiology ($\boxed{X^2}$ (2, N = 89) = 18.72, *p* = .0001), such that children with conductive hearing loss were more likely to have unilateral hearing loss, and children with sensorineural hearing loss were more likely to have a bilateral loss. All children with mixed hearing loss (n = 8), though excluded from statistical analysis due to low N, had bilateral hearing loss. The chi-square tests further showed that amplification was related to laterality ($\boxed{X^2}$ (2, N = 98) = 17.55, p = .0002) and degree of hearing loss ($\boxed{X^2}$ (4, N = 88) = 28.76, p < .0001). Specifically, children with bilateral hearing loss were more likely than children with unilateral hearing loss to use a hearing aid or cochlear implant; no child with unilateral hearing loss used a cochlear implant, and many children with unilateral hearing loss used no amplification. Regarding degree of hearing loss, children with severe-to-profound hearing loss were more likely to use a cochlear implant than children with mild or moderate hearing loss.

Taken together, the results in this set of analyses highlight the notable interconnectedness among early health and development (i.e. health issues, prematurity, and developmental delays), and audiological characteristics (i.e. links among laterality, etiology, amplification, and degree of hearing loss).

2.3.2 Predictors of Vocabulary Delay

We next turn to the relationship between these variables and children's productive vocabulary, as measured by the CDI. Figure 2 shows the vocabulary scores of children in our sample relative to norms for hearing children for each CDI form. Descriptively, we found widespread vocabulary delays, with the majority of DHH children testing around or below the 25th percentile for hearing children (based on WordBank norms; Frank et al., 2017).

As noted above, the two CDI forms differ in how many vocabulary items they contain. To take this into account, we establish the difference (in months) between the child's chronological age and their predicted age based on their productive vocabulary, derived from the WordBank norms (Frank et al., 2017), rather than using the raw vocabulary scores. We call this derived variable *vocabulary delay*.

More specifically, to compute a child's predicted age from their vocabulary score, we used the 50th percentile for productive vocabulary from WordBank data for typically-developing infants (Frank et al., 2017) to create binary logistic growth curves separately for the "Words and Gestures" (WG) and "Words and Sentences" (WS) versions of the CDI for American English and Mexican Spanish[2]. For each child, we took the number of words they produced (spoken and/or signed, though the latter was only provided for children using Total Communication (n = 18) as all others were reported to exclusively use spoken language). We then divided this production score by the number of words on the instrument, to give us the proportion of words produced. We used this proportion in an inverse prediction from the binary logistic regression curves to generate a predicted age. That is, for each possible CDI score, the growth curve provided the age that the score would be achieved for the 50th percentile trajectory. Finally, we subtracted the predicted age from each child's chronological age to calculate their vocabulary delay. However, for children producing 0 words, this approach was not appropriate due to the long tails on the growth curves. Thus, for this subset of children, we took the x-intercept from Wordbank (8 months for English, and 9 months for

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[2] Number of hearing children in normative sample for each growth curve: WG-English=1071, WG-Spanish=760; WS-English=1461, WS-Spanish=1092

Spanish), and subtracted that value from the child's chronological age to get their vocabulary delay.

To look at the relationship between our predictor variables and CDI scores, we next conducted multiple linear regression, using vocabulary delay as our outcome variable. Children who were too young for the CDI version they were administered (n = 7) were excluded from this portion of the analysis, as was the adopted child due to concerns about comparing their score to the American English CDI norms.

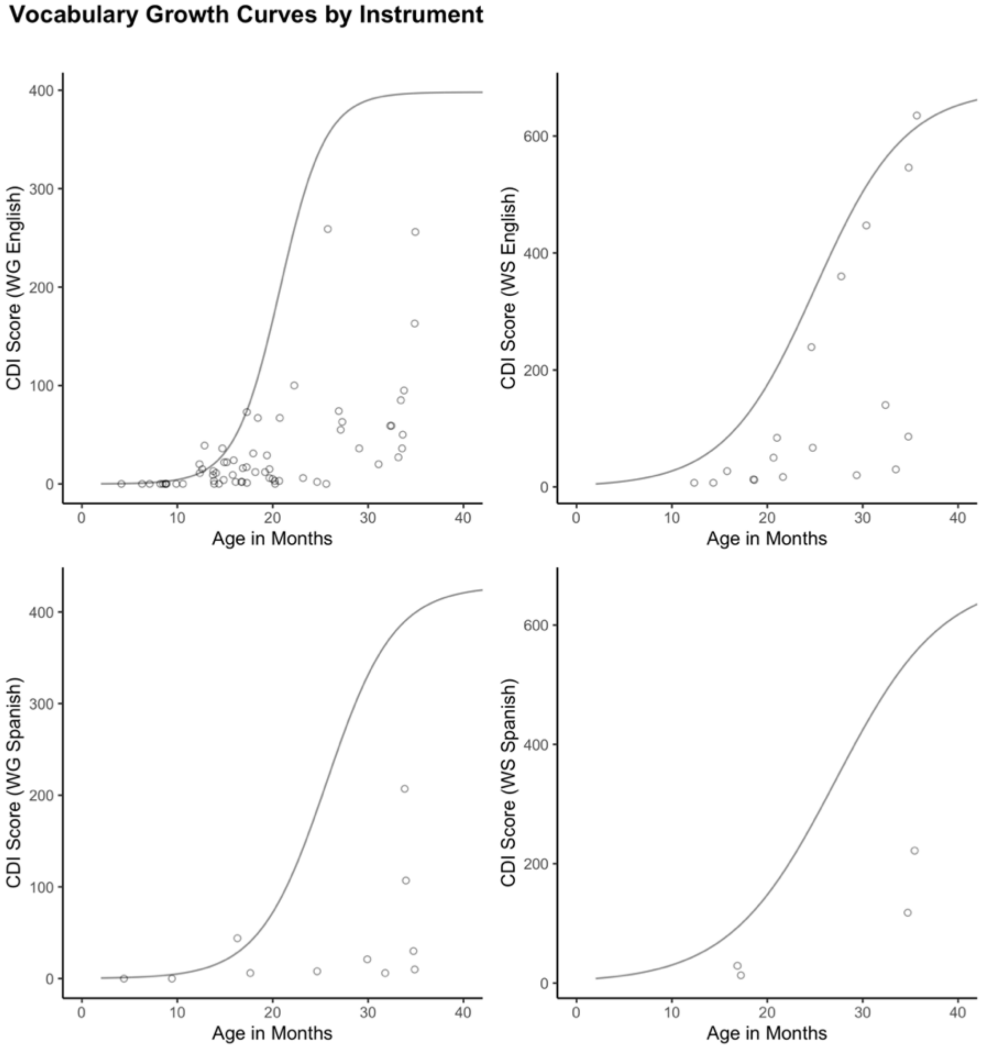

Figure 2: Lines show the growth curves created from Wordbank 50th percentile data. Left panels show Words & Gestures; right panels show Words & Sentences. Top row is American English data; bottom row is Mexican Spanish data. Dots represent vocabulary scores of individual DHH children in the sample.

Our full regression model included all variables: Vocabulary Delay ~ Gender + Developmental Delay + Health Issues + Premature Birth + Laterality + Degree + Amplification + Communication + Meets 1-3-6 + Services Received Per Month + Language Background.

This model accounted for significant variance in vocabulary delay (adjusted-R^2 = 0.59, $p < .001$). We next performed stepwise model comparison using stepAIC (MASS) to pare down the model. This process selects only the predictors which incrementally improved model fit, measured by Akaike's Information Criterion (AIC). We started model selection with the full model, as described above. We then filtered out data from children for whom Meets 1-3-6 (n = 5) or Degree (n = 12) was unknown, as this stepwise AIC approach does not permit missing values across predictors. Since this initial filtered analysis found that Degree and 1-3-6 did not improve model fit, we manually removed the Degree and 1-3-6 terms from the model selection so that the 14 participants with missing cases for these variables could be retained[3].

Based on this iterative process, we arrived at the following final model: Vocabulary Delay ~ Age + Laterality + Amplification. No other variables from the full model above significantly improved model fit, and are thus not discussed further. Our final model accounted for significant variance in children's vocabulary delay to a nearly identical degree as the full model (adjusted-R^2 = 0.58, p = < .001, see Table 5 & Figure 5.A). We found significant main effects for Age, Laterality, and Amplification, such that older age, bilateral hearing loss, and no amplification predicted greater vocabulary delays. Compared to children with no amplification, children with cochlear implants

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[3] 3 participants had missing values for both 1-3-6 and Degree. For transparency, we note that the model fitted with only complete cases of Degree did include a non-significant main effect of Developmental Delay. However, ANOVA revealed that including a Developmental Delay term did not significantly improve model fit when including the 14 participants without Degree information.

had a 3.58 months smaller spoken vocabulary delay (*p* = .019), and similarly children with hearing aids had a 3.89 months smaller delay (*p* = .001). Children with unilateral hearing loss had a 3.03 months smaller delay (*p* = .009) than children with bilateral hearing loss. For Age, the model predicted a 0.55 months *larger* vocabulary delay (*p* < .001) for each additional month of age.

Given our first set of results regarding relationships among several of these variables (e.g., laterality and amplification), we tested for collinearity by computing the model's VIF (variance inflation factor). This revealed low levels of collinearity among predictors in our final model (James et al., 2013). In sum, the analyses in this section revealed that over half of the variance in DHH children's vocabulary scores was explained by their age, whether they receive amplification, and whether their hearing loss was unilateral or bilateral.

Table 5: Unstandardized Beta Weights (Months of Vocabulary Delay) for the Model of Vocabulary Delay Selected by AIC.

term	estimate	std.error	statistic	p.value
(Intercept)	-0.51	1.74	-0.29	.770
Laterality (Unilateral)	-3.03	1.14	-2.66	.009
Amplification (Cochlear Implant)	-3.58	1.49	-2.40	.019
Amplification (Hearing Aid)	-3.89	1.14	-3.41	.001
Age (months)	0.55	0.06	9.64	< .001

2.3.3 Success in Meeting 1-3-6 Guidelines

Perhaps of greatest importance to clinicians and policymakers is the implementation and effect of existing policies. Although 1-3-6 status was not included in our final model predicting vocabulary delay through our model selection process, its demonstrated importance for language outcomes (Yoshinaga-Itano et al., 2018) merits further discussion. To this end, we provide a brief description of the implementation of 1-3-6 in our sample, examine its effect on vocabulary delay, and describe the results of exploratory linear regression models for age at diagnosis and age at intervention. Overall, 36% of our sample met 1-3-6 guidelines for early diagnosis and intervention. Breaking this down further, among the children for whom screening information was available (n = 68), 100% were screened at birth or during NICU stay. In our sample, 69% of children received diagnosis by 3 months of age, and 38% began early intervention by 6 months of age (see Figure 3).

We first tested the link between 1-3-6 and vocabulary directly. An independent samples t-test showed that children who did not meet 1-3-6 guidelines had significantly larger vocabulary delays than children who met 1-3-6 guidelines ($t(66.29) = 2.66$, $p = 0.01$; see Figure 4). On average, the group that did not meet 1-3-6 guidelines was 3.71 months more delayed with regard to vocabulary (relative to the same 50th percentile benchmark described above).

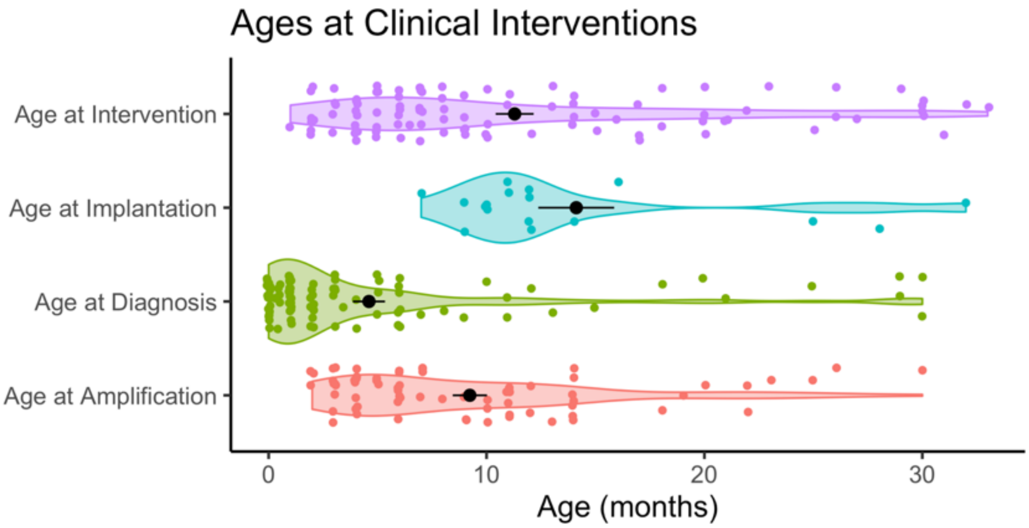

Figure 3: Age at diagnosis, intervention amplification, and cochlear implantation across participants. Each dot represents the age that one child received the clinical service; violin width reflects data distribution. Black dots and whiskers show means and standard errors. Not all children received amplification (hearing aids) or implantation (cochlear implants).

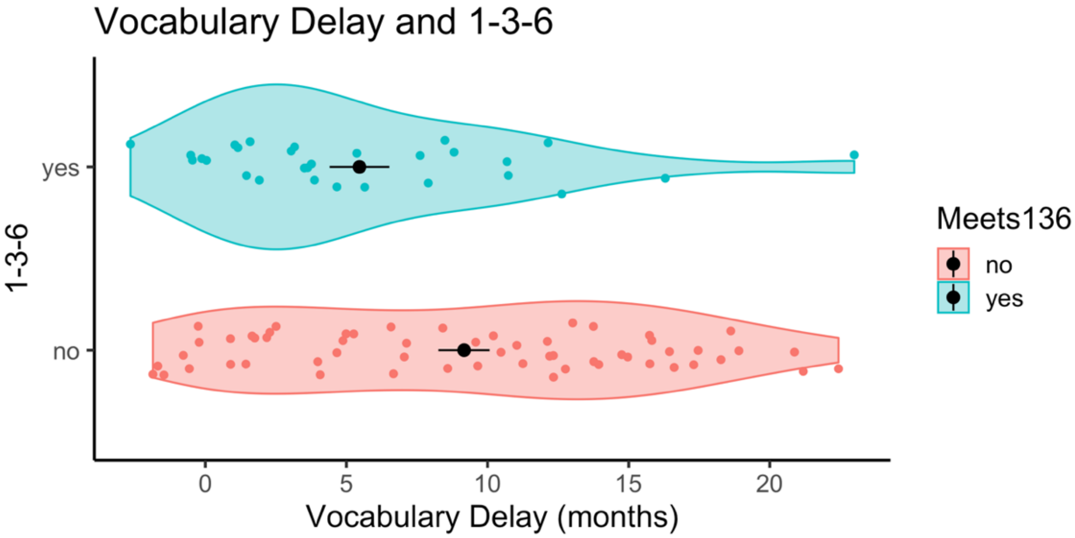

Figure 4: Estimated vocabulary delay for children who meet 1-3-6 guidelines for diagnosis/intervention (top) and children who do not (bottom). Each dot represents one child in the sample; violin width reflects data distribution. Black dots and whiskers show means and standard error.

To better understand implementation of 1-3-6 guidelines, we next turned our focus to factors influencing the timing of diagnosis and intervention. We conducted two linear regressions, one for predicting age at diagnosis and one for age at intervention. Model selection followed the same stepwise AIC-based process as described in the preceding section.

For age at diagnosis, we included the set of child-specific factors that would be relevant *before* diagnosis of hearing loss (e.g., we excluded amplification type because children did not receive amplification prior to hearing loss diagnosis.) We began with: gender, degree, developmental delay, health issues, prematurity, laterality, language background, and etiology.

The best fitting model was: Age at Diagnosis ~ Health Issues + Language Background + Laterality, with significant main effects of Health Issues and Language Background (see Table 6 & Figure 5.B). This model accounted for 15.34% of the variance in age at diagnosis (*p* = .002). Average age at diagnosis was 4.60(7.19) months. Relative to English-speaking families, children from Spanish-speaking families were diagnosed 6.18 months later (*p* = .002). Children with health issues were diagnosed 3.65 months later than children without health issues (*p* = .01). One possibility for this last predictor is that the health issues caused hearing loss *later* in infancy; in our sample, 16 of the 36 children with health issues reported conditions that can in some cases cause acquired hearing loss (i.e., meningitis, sepsis, jaundice, seizures, hydrocephalus, MRSA, anemia, frequent fevers, cytomegalovirus).

Table 6: Unstandardized Beta Weights (Months) for the Model of Age at Diagnosis Selected by AIC.

term	estimate	std.error	statistic	p.value
(Intercept)	9.08	1.94	4.68	< .001
Health Issues (yes)	3.65	1.44	2.53	.013
Language Background (English)	-6.18	1.93	-3.20	.002
Laterality (Unilateral)	-2.21	1.60	-1.38	.170

We repeated this model selection process for age at intervention. In addition to the variables used to fit the diagnosis model, we included age at diagnosis. The best fit model was: Age at Intervention ~ Premature Birth + Degree + Age at Diagnosis + Language Background (R^2=0.43 , *p* < .001; See Table 7 & Figure 5.C), with significant main effects of degree and age at diagnosis. Prematurity (ß = 3.79, p = .06) and language background (ß = -1.37, p = .51) were not significant predictors on their own, but their inclusion improved model fit. Average age at intervention was 11.29(8.63) months. More severe hearing loss predicted earlier intervention, such that for every additional 10 dB HL, predicted age at intervention was 1 month earlier (*p* < .01). With regard to age at diagnosis, for every month diagnosis was delayed, intervention was delayed by 2.80 weeks (*p* < .01). Taken together, these analyses reveal that children's audiological characteristics, comorbid diagnoses, and language background contribute to delays in both diagnoses and intervention. We return to this point in the discussion.

Table 7: Unstandardized Beta Weights (Months) for the Model of Age at Diagnosis Intervention by AIC.

term	estimate	std.error	statistic	p.value
(Intercept)	14.63	2.76	5.29	< .001
Degree of Hearing Loss	-0.09	0.03	-3.02	.003
Premature (yes)	3.79	1.96	1.93	.057
Age at Diagnosis	0.65	0.10	6.25	< .001
Language Background (English)	-1.37	2.05	-0.67	.506

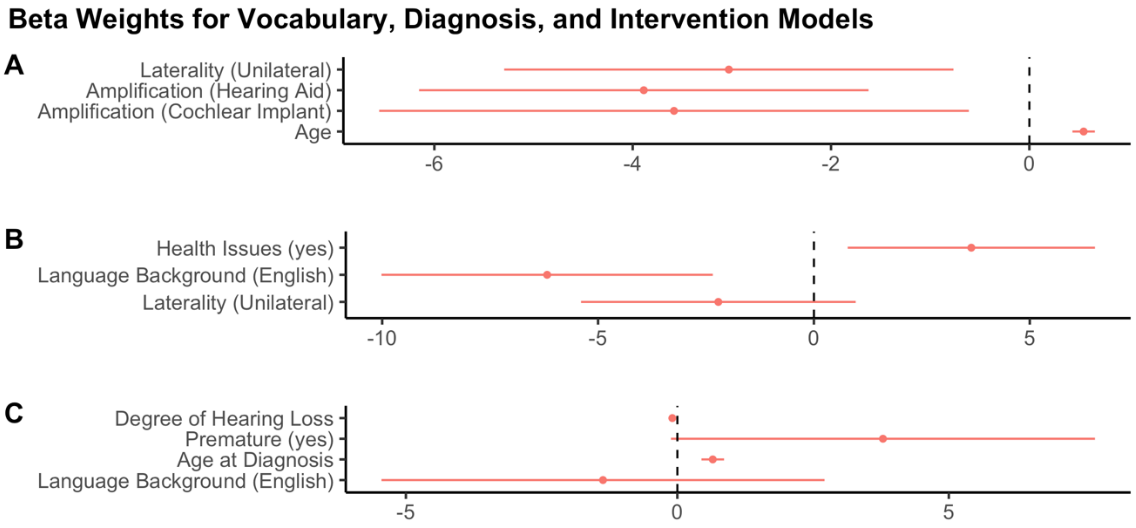

Figure 5: Unstandardized coefficients (measured in months) with 95% confidence intervals for the models selected by AIC for: (A) vocabulary delay, (B) age at diagnosis, (C) age at intervention.

2.4 Discussion

In this study, we examined the demographic, audiological, and clinical characteristics of 100 young DHH children in North Carolina. We documented the distribution of these characteristics and explored the relationships between these variables, vocabulary, diagnosis, and intervention. In prior work with tightly controlled samples, the variables studied here have been shown to be relevant for language development, but their effects have rarely been examined in the full heterogeneity they naturally occur within. We took this big-tent approach by including any children receiving services for hearing loss.

Returning to our original three questions, we asked first: how are child-level variables intertwined? We found significant structure across many of the variables, suggesting that in a real-world sample of children with hearing loss, many factors are intrinsically not dissociable. This was particularly true for many of the auditory characteristics and comorbid diagnoses. To our knowledge, this paper provides the first population-based documentation of this distribution. We next asked whether these characteristics can predict vocabulary outcomes for DHH children. We found that a model including only children's age, laterality of hearing loss, and amplification type best accounted for the variability in vocabulary outcomes. Finally, we asked how successful the 1-3-6 guidelines were for early detection and intervention, both in terms of improving child outcomes and ensuring timely diagnosis and intervention. Here, we found that children who met 1-3-6 guidelines indeed had a smaller vocabulary delay than those who didn't. However, only 36% of children met these guidelines. Our results highlight family- and health-related variables that accounted for significant variability in when children received diagnosis and/or intervention.

We believe the inherent complexity in these results is an important piece of understanding vocabulary outcomes within the diverse population of DHH children.

We next highlight some implications of this study for future research and clinical practice.

2.4.1 How are child-level variables intertwined?

This study contributes to the literature by quantifying the distribution and co-occurrence of demographic, audiological, and intervention characteristics in our broad sample, which includes many children often excluded from research. In our sample, we found significant overlap among demographic, audiological, and clinical variables. To highlight a few of these findings, prematurity, health issues, and developmental delay frequently co-occurred, such that children with one of these factors were more likely to have the others, consistent with prior research (Luu et al., 2016; Pierrat et al., 2017). Given that the constellation of comorbid conditions is so varied (76 unique conditions in our sample of 100 children; see Table 1), an important direction for future research is whether cognitive and social abilities, as well as families' treatment resources, are predictive of language outcomes across conditions.

We also found that children with developmental delays (e.g., Down syndrome) were much more likely to use a total communication approach than DHH children without developmental delays (i.e., total communication used by 62.50% of DHH children with developmental delay vs. 9.76% of those without). That is, use of total communication was more likely for children already at greater risk for verbal delays. Quantifying this confound is an important contribution of this work, as it calls for tempering the interpretation of correlational studies finding links between total communication and language delays (Geers et al., 2017).

The relationships we found among variables were more confirmatory than surprising, particularly those reflecting known causal links (e.g., increased health issues in children born premature). Nevertheless, they should caution us to think critically about how we construct samples for controlled lab experiments. For example, if an eyetracking experiment has a sample of typically-developing pediatric cochlear implant users with bilateral, severe-to-profound hearing loss, such a subsample may only represent roughly 14% of the DHH population. Such considerations are important for properly representing and supporting DHH children and their families. This becomes doubly important in the context of interpreting language outcomes like vocabulary.

2.4.2 Predicting vocabulary outcomes

In our sample, 87.78% of DHH children fell below the 50th percentile for vocabulary, indicating that a large majority of this sample is behind a normative sample of their hearing peers in word learning. This disadvantage can have lasting consequences in the lives of DHH children (Karchmer & Mitchell, 2003; Qi & Mitchell, 2012), highlighting the importance of understanding what factors contribute to it.

In contrast to our predictions, the best model predicting vocabulary delay had just a few variables: age, amplification, and laterality. We did not find that gender, developmental delay, health issues, premature birth, degree of hearing loss, communication modality, 1-3-6 status, number of services per month, or language background significantly improved model fit. Notably, we see that the spoken vocabulary delay widens with age, indicating that the *rate* of spoken vocabulary acquisition is slower for DHH children. Given that none of the children here use sign language (which can ensure earlier language access), this vocabulary delay is likely to have knock-on effects for language development more broadly, alongside implications for public policy.

2.4.3 Predicting early diagnosis and intervention

Our exploration of the implementation of 1-3-6 guidelines revealed that only 35.79% of children met the EHDI guidance for diagnosis by 3 months and intervention by 6 months. Our results were consistent with prior work (e.g., Yoshinaga-Itano et al., 1998; Ching et al., 2013), finding that children who met the guidelines were 3.71 months *less* delayed in spoken vocabulary than children who were late to receive diagnosis and/or services. By dint of accepting all children receiving early intervention services in one state, our dataset let us delve deeper into *who* received on-time diagnosis and intervention.

2.4.3.1 Diagnosis

Having health issues or a non-English language background predicted later diagnosis. Children with health issues were diagnosed 3.65 months later than infants without health issues. For a small fraction of cases, this may have been because health issues caused acquired hearing loss, delaying its identification. Of course, some situations may require families and medical providers to prioritize treatment for certain health issues (e.g., surgery for congenital heart defect) over diagnostic audiology services. That said, our results raise the possibility that clinician awareness of increased delays in language linked to the prevalence of health issues may facilitate improvements in timely diagnosis.

Language background too predicted age at diagnosis, such that infants from Spanish-speaking families were diagnosed 3.79 months later than infants from English-speaking families. This may be due to cultural differences in attitudes towards deafness (Caballero et al., 2017; Rodriguez & Allen, 2020; Steinberg et al., 2003) or a lack of linguistically accessible and culturally appropriate audiology services. Only 5.6% of American audiologists identify as bilingual service providers (ASHA, 2019), and services from a monolingual provider may be insufficient, particularly in obtaining the child's case history and providing recommendations for follow-up services (Abreu et al., 2011).

2.4.3.2 Intervention

As expected, more severe hearing loss predicted earlier intervention. This may be due to parents and clinicians adopting a wait-and-see approach to intervention for children with some residual hearing, despite associations between mild-to-moderate hearing loss, and language delays and academic challenges (Blair et al., 1985; Delage & Tuller, 2007). Early intervention may help offset these associations.

Age at start of services was also associated with age at diagnosis: for each month diagnosis was delayed, intervention was delayed by 2.80 weeks. Ching et al. (2013) found that age at intervention predicted better outcomes for DHH children, above and beyond age at diagnosis. Of course, these two variables are related, underscoring the importance of early diagnosis for putting children in the pipeline towards earlier intervention.

Finally, it's important to note that this sample is composed of children receiving birth-to-3 services. Less than 38% of our sample of children in early intervention meet the 6-month EHDI benchmark. Given that only about 67% of children with hearing loss enroll in early intervention services (CDC, 2018), our data suggest that the actual proportion of DHH children who receive intervention by the EHDI-recommended 6 months may be closer to 25%. These children may not receive clinical support until school-age or later, exacerbating concerns for language development, which lays an important foundation for literacy and academic success (Hemphill & Tivnan, 2008; Stæhr, 2008).

2.4.4 Educational and Clinical Implications

Despite high rates of newborn hearing screening in North Carolina, and even relatively high rates of diagnosis by 3 months (66/100 children in our sample), most children did not meet the 1-3-6 guidelines. Based on our analyses, we have the following recommendations for increasing attainment of 1-3-6 guidelines:

- Frequent hearing screenings for children receiving medical or therapeutic care for health issues.
- Service coordination for families balancing multiple co-occurring conditions.

- Expansion of bilingual clinicians both in-person and for teletherapy to provide therapy and service coordination to non-English-speaking families.
- Provision and encouragement of early intervention services for children with mild to moderate hearing loss.

Additionally, the vast majority of children in our sample experienced vocabulary delays (relative to hearing peers), and studies of spoken vocabulary development in older DHH children suggest that they may not catch up (Lund, 2016). This should set clinicians and educators on high alert. As early intervention predicts vocabulary outcomes across multiple studies (including this present study and e.g., Vohr et al., 2008; Ching, Dillon, Leigh, & Cupples, 2018), ensuring intervention by 6 months for all DHH children may be one way to address spoken vocabulary deficits. Another option may be the provision of structured, accessible language input (i.e., sign language) even prior to intervention or amplification, potentially mitigating negative effects of auditory deprivation on language skills (Davidson et al., 2014; Hassanzadeh, 2012). While learning sign language may pose a challenge for some families for myriad reasons (as underscored by its absence as a communication modality within our sample), we nevertheless highlight its potential as an important language support for DHH children and their families.

2.4.5 Limitations and Opportunities for Future Work

This study represents an important first step in quantifying variability in demographic characteristics, language outcomes, and 1-3-6 attainment. At the same time, it is exploratory, has limited geographic scope, and analyzed data from a (deliberately) high-variability sample.

Given our exploratory analyses, there were many possible analytic routes. We encourage interested readers to explore further analyses using the data and/or code provided on our OSF page.

This sample is composed only of children in North Carolina. While certain factors vary by country and by state (e.g., diagnosis and early intervention practices; NAD, n.d.), our sample largely resembles the national DHH population in terms of degree of hearing loss, percentage of children with additional disabilities, cochlear implant and hearing aid use, language background, and gender (Blackorby & Knokey, 2006; Gallaudet Research Institute, 2014). It did diverge from the national sample in communication modality: our sample had no signers while 20% of DHH children have sign as their primary modality (Gallaudet Research Institute, 2014). A similar naturalistic study in regions where sign language access for DHH children is more common (e.g., Washington D.C.) would be a welcome addition to the present work, in illuminating the effects of different clinical and demographic factors in a signing population. One further limitation to our analyses and to assessing representativeness of the sample is that race and socioeconomic status information was not available.

Finally, the considerable variability in the sample did not allow us to easily isolate effects of different factors (e.g., degree vs. amplification). This reflects real-world variability and would be best addressed by larger sample sizes. As researchers continue to study influences on vocabulary in DHH children, a meta-analytic approach too may be able to better estimate effect sizes within the varied outcomes of this heterogeneous population.

2.5 Conclusion

The present study explored interrelations among demographic and audiological characteristics, vocabulary outcomes, and clinical milestones within a diverse sample of 100 DHH children enrolled in early intervention services in North Carolina. Our population-based description underscores heavily interlocking demographic, audiological, and clinical characteristics (e.g., communication approach and presence of developmental delays). Our models highlight the outsized roles of age, amplification, and laterality relative to other predictors, together accounting for over half of variance in productive vocabulary. We also explicitly examined the roles of prompt achievement of early intervention milestones on vocabulary. We found that overall, this sample showed vocabulary delays relative to hearing peers, and room for improvement in rates of early diagnosis and intervention in particular. This in turn highlights potential paths forward in ensuring that regardless of hearing status, we are able to provide language access and early childhood support to help children attain their potential.

3. The Role of Vision in the Acquisition of Words: Vocabulary Development in Blind Toddlers

3.1 Introduction

Descriptions of early word learning often invoke visual scenes: a messy living room, a rabbit jumping across a trail. At some level, word learners are thought to take the linguistic input, deduce referents in a visual sea of possibilities, and connect this input to intended meaning. How do young learners do this? Some propose they look for visually salient objects (Yu & Smith, 2012); others suggest central roles for following speakers' gaze or intent (Brooks & Meltzoff, 2008; Tomasello, 2003). These strategies could help constrain referent possibilities given novel word and ambiguous visual input, but such approaches do not work for all words, let alone all learners.

If visual input is integral to word learning, then its absence should lead to pronounced differences in language abilities. However, blind adults perform comparably to sighted adults on many language tasks, and on some tasks, demonstrate faster language processing than sighted adults (Bottini et al., 2022; Loiotile et al., 2020; Röder et al., 2003). But are these equivalencies or advantages present in the earliest stages of language development, or do they emerge over time? One way to tackle this question is to study vocabulary development in congenitally blind children. We ask: does a radically different experience of perceiving the world leads to differences in how we begin to learn words?

3.1.1 Potential Challenges for the Blind Learner

Though blind adults are skilled language users, their early lexicon (in terms of vocabulary size and composition) remains unclear. Before returning to this, we discuss several social and motor supports of early language development for sighted children that are absent or delayed in blind children.

The ability to reach for, grasp, and manipulate objects of interest has been argued to support word learning. For instance, words with easily manipulable referents are more frequent in children's early productive vocabulary than non-manipulable ones (Nelson, 1973). Additionally, children's object manipulation may highlight children's attentional focus for parents, eliciting more object naming (Luo & Tamis-LeMonda, 2016; Tamis-LeMonda et al., 2013; West & Iverson, 2017; West & Rheingold, 1978). Relatedly, held objects dominate infants' visual field (Yu & Smith, 2012). Taken together, these lines of work suggest infants' object manipulation may facilitate word learning.

In blind children, grasping and reaching are delayed (Fraiberg & Fraiberg, 1977; Norris, 1957; Pérez-Pereira, 1994). While sighted children reach towards a seen object at around 4–6 months (von Hofsten, 1989), a parallel ability, reaching towards an object making noise, does not emerge in blind infants until around 8 months, similar to sighted children's timeline for hand-ear coordination (Fraiberg & Fraiberg, 1977). If reaching for and manipulating objects cues parents to their infant's interest, then blind infants may not receive language input tailored to the locus of their attention, which in turn may influence early word learning.

Social interaction provides another support for children's early word learning. Parents often talk about what they or their child are looking at (Tomasello, 2003; Yurovsky et al., 2013). In turn, following speakers' gaze may help children deduce communicative intent (Brooks & Meltzoff, 2008; Carpenter et al., 1998; Meltzoff & Brooks, 2009). In sighted infants, gaze-following is linked with later vocabulary size (Brooks & Meltzoff, 2008); in blind infants, gaze is not an accessible word meaning cue. Likewise, pointing is linked with children's language ability (Colonnesi et al., 2010; Moore et al., 2019), perhaps because it too directs a conversation partner's attention. Sighted infants shift their gaze to the direction of the point reliably by around 10–12 months of age (Carpenter et al., 1998) and begin pointing themselves at around the same age (Moore et al., 2019). Pointing is argued to support word learning by serving as a naming "request" (Lucca & Wilbourn, 2019); by 18 months, labels given after infants point are better learned (Lucca & Wilbourn, 2018). By contrast, in naturalistic settings, 14–24-month-old blind infants rarely point, instead gesturing with an open palm towards proximal objects (Iverson et al., 2000), though the link between this behavior and word learning has not been empirically tested.

Reaching, gaze-following, and pointing are useful cues for establishing joint attention, wherein two individuals are simultaneously focused on each other and an object or event. Joint attention may provide referentially transparent language input, which can facilitate word learning (Tomasello & Farrar, 1986). For blind children however, joint attention is often delayed relative to sighted peers (Bigelow, 2003; Dale et al., 2014Perez-

Pereira & Conti-Ramsden, 1999). This suggests that any word learning benefits of joint attention too may be reduced or delayed for blind children.

3.1.2 Vocabulary Development in Blind Children

The potential challenges for blind learners enumerated above are intended to showcase the various ways that vision might influence early word learning. If the highlighted skills are indeed critical, we would expect profound language deficits in this population. However, prior work on productive vocabulary development in blind children is inconclusive. Some research finds that blind infants learn words on roughly the same timeline as sighted infants (Landau & Gleitman, 1985; Wilson & Halverson, 1947); others find delays in first-word production (Brambring, 2007; Fraiberg & Fraiberg, 1977; Iverson et al., 2000; Moore & McConachie, 1994; Mulford, 1988). The existence and extent of vocabulary delays may of course be influenced by a host of other factors, such as severity of the vision diagnosis, etiology, comorbid diagnoses, etc. (Greenaway & Dale, 2017). Understanding which blind children may be at particular risk for language deficits or delays remains an important clinical goal.

3.1.2.4 Vocabulary Composition

The composition of blind children's first words has been reported as largely similar to that of sighted children. Like English-learning sighted children, English-learning blind children's first words include a large proportion of nouns (Andersen et al., 1984; Bigelow, 1986; Dunlea, 1989; Landau & Gleitman, 1985). Some studies have found that blind children may have a weaker noun bias (Mcconachie & Moore, 1994; Mulford, 1988;

Norgate, 1997), which may be due to fewer "point-and-look" learning episodes relative to sighted children (Norgate, 1997); others report fewer words for distal objects (Bigelow, 1987). These differences in vocabulary composition are small in magnitude and inconsistent across the literature. More strikingly, despite lacking visual access, blind children preschool age and up have been reported to use visual terms like "red" (DeMott, 1972; Harley, 1963; Landau & Gleitman, 1985).

While existing research on vocabulary development in blind children provides a valuable foundation, each of the studies cited above is based on a limited sample size, typically N<10. This stems from the challenges of sampling young blind children without additional cognitive deficits; congenital blindness often occurs as part of syndromes with wide-ranging symptoms (Garcia-Filion & Borchert, 2013). Expanding this work is an important goal, both for improving early intervention services for blind children, as well as better understanding how visual perception contributes to word learning more broadly. In what follows, we explore the role of vision in word learning using a standardized vocabulary measure administered to 40 blind children. We ask whether blind children have productive vocabulary differences relative to their sighted peers, both in quantity (how many words they produce), and composition, (which words they produce).

3.2 Methods

Approximately 1/10,000 children is born with severe to profound visual impairment (Gilbert & Awan, 2003). Given the low incidence of this condition, our sample includes 40 young, congenitally blind children (7–57 months, M: 24.01 (12.46) months). To focus specifically on the role of vision in language development, children met inclusion criteria if they (1) were exposed to >75% English at home, (2) had *no more than minimal light perception* in both eyes, (3) had no co-occurring cognitive or developmental diagnoses, and (4) had no history of frequent ear infections or hearing loss; see Table 8 for vision diagnosis specifics. Data from 3 participants were collected but excluded due to bilingualism (N=2), hearing loss (N=2), and/or co-occurring cognitive or developmental diagnoses (N=1). Participants were recruited in the United States and Canada via pediatric ophthalmology clinics, early intervention and preschool programs for blind children, social media, and word of mouth. Many participants contributed data at multiple timepoints, for a total of N=70 total datapoints (1–5 per child, M: 1.75); to avoid overrepresenting participants, we use only data from the oldest timepoint for analyses, with a few exceptions, noted below. Data from 11 participants were originally described in Herrera (2015). Participant demographics are available in Table 9.

Parents of each child in our sample completed the MacArthur-Bates Communicative Development Inventory (CDI). The CDI is a parent-report instrument predominantly used to assess children's productive/receptive vocabulary alongside a few items regarding other aspects of early language; we focus on the vocabulary data here. On the Words and Gestures version of the form (WG; normed for 8–18-month-olds), parents indicate whether their child understands and/or produces each of the 398 vocabulary items. On the Words and Sentences version (WS; normed for 16–30-month-olds), parents indicate whether their child produces each of the 680 vocabulary items.

Table 8: Severity of visual impairment and vision diagnoses for each child in the sample.

Diagnosis	N_{severe}	N_{profound}	$N_{\text{severity unspecified}}$	**Etiology**
Optic Nerve Hypoplasia	8	3	0	Central
Not specified	2	2	3	
Leber's Congenital Amaurosis	3	1	0	Peripheral
Cataracts	3	0	0	Peripheral
Microphthalmia	3	0	0	Peripheral
Anopthalmia	0	2	0	Peripheral
Multiple	2	0	0	
Ocular albinism	1	1	0	Peripheral
Retinal Detachments	1	1	0	Peripheral
CVI	1	0	0	Central
Fused Eyelids	1	0	0	Peripheral
Optic Pathway Glioma	1	0	0	Central
Retinopathy of Prematurity	0	1	0	Peripheral

Table 9: Demographic characteristics of the 40 participants in the study.

Variable	**Range and Mean, or Ns**
Age (months)	7-57 months (mean (SD): 24.01 (12.46))
Receptive Vocabulary* (CDI)	0-391 words (mean (SD): 59.94 (80.92))
Productive Vocabulary (CDI)	0-680 words (mean (SD): 141.8 (223.91))
Gender	Female (15); Male (25)
Maternal Education	High School (2); Associate's Degree or Some College (11); Bachelor's degree (18); Graduate degree (8); Missing (1)
Child Race	American Indian or Alaska Native (1); Black or African American (5); Southeast Asian or Indian (1); White (20); Multiracial or Other (2); Missing data (11)
Child Ethnicity	Hispanic or Latino (4); Not Hispanic or Latino (23); Missing (13)

*** Receptive vocabulary scores only measured on Words and Gestures version of CDI; all Words and Sentences administrations excluded from these values.**

Normative data for the CDI is available from English and many other languages on WordBank (e.g., Frank, Braginsky, Yurovsky, & Marchman, 2017), an open database of CDI data. While the CDI has not been validated for blind children, it has been used successfully in other special populations, such as Deaf/Hard-of-Hearing children (Thal, Desjardin, & Eisenberg, 2007), late talkers (Heilmann, Weismer, Evans, & Hollar, 2005), and children with Down syndrome (Miller, Sedey, & Miolo, 1995). Critically, in many of these populations, the CDI production measure has been validated for "off-label" usage above the chronological age for which the CDI has been normed for typically-developing children (Heilmann et al., 2005; Miller et al., 1995; Thal et al., 2007).

3.3 Results

3.3.1 Analysis Plan

Our results are organized around answering the two questions set out above: do blind and sighted children differ in how many words they say at a given age, and do they differ in the composition of those vocabularies. To address the first question, we compared blind children's vocabulary on the CDI relative to norms derived from sighted children of the same age. We then considered a variety of child-level characteristics to get a better understanding of what may contribute to the overall delay we observe, as well as an analysis of delay size with age. For these analyses we used logistic regression curves, Wilcoxon Tests, and linear regression, as relevant. To address the second question, we matched for vocabulary size and compared blind and sighted children's vocabulary composition across a range of factors: word length, part of speech, semantic category, concreteness, interactiveness, and perceptual modality (details below). For these analyses we used Bonferroni-corrected Wilcoxon Tests and logistic regressions. Previewing the results to this question, we found very consistent vocabulary composition across our blind and sighted groups. We describe the findings in full detail below, and provide the data and code used to generate this paper on OSF. These analyses were not preregistered.

3.3.2 Do blind children and sighted children show similar word production trajectories?

To analyze whether blind children produce a similar *quantity* of words to their sighted peers, we used a large set of vocabulary production data from Wordbank. The normative dataset contains data from 6574 children learning American English (downloaded 2022-11-05 from Wordbank). As noted above, the two CDI forms differ in how many vocabulary items they contain. To take this into account, we established the difference (in months) between the child's chronological age and their predicted age based on their productive vocabulary, derived from the WordBank norms (Frank et al., 2017), rather than using the raw number of words checked off on the instrument. We call this derived variable, measured in months, *vocabulary difference*.

Following the procedure in the preceding chapter (Campbell & Bergelson, 2022), to compute a child's predicted age from their vocabulary score, we used the Wordbank's 50th percentile for productive vocabulary for sighted infants (Frank et al., 2017) to create two binary logistic growth curves (for the WG and WS versions of the CDI). For each child, we took their productive vocabulary score, as reported on the CDI. We then divided the number of words produced by the number of possible words on the instrument (WG or WS), to give us the proportion of words produced. We used this proportion in an inverse prediction from the binary logistic regression curves to generate a predicted age. That is, for each possible CDI score, the growth curve provided the age that the score would be achieved for the 50th percentile trajectory. Finally, we subtracted the predicted age from each child's chronological age to calculate their vocabulary delay or advantage; see Figure 6 for a visual representation of this procedure. However, for children producing 0 words (N=9), this approach is not appropriate due to the long tails on the growth curves.

Thus, for this subset of children, we took the x-intercept from Wordbank (8 months), and subtracted that value from the child's chronological age to get their months difference.

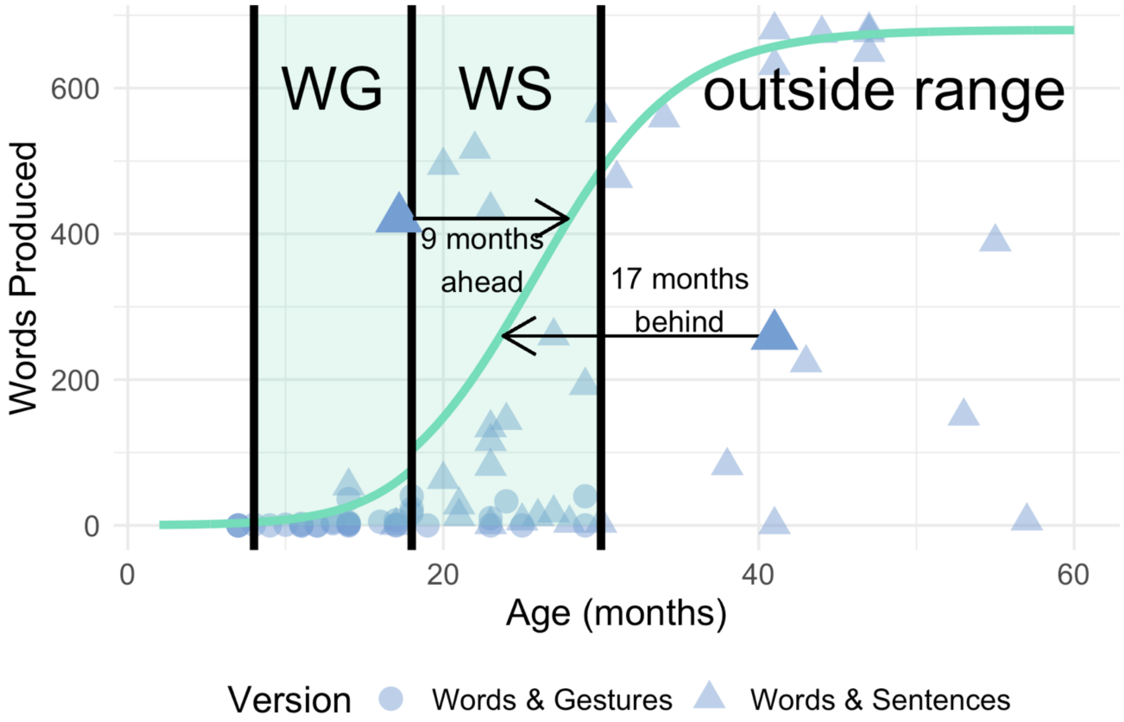

Figure 6: Visual representation of the months-difference calculation. Shaded region shows the age range covered by the Wordbank norms. Teal line depicts the logistic growth curves constructed from the Wordbank 50th percentile data. Each point represents a blind child's productive vocabulary score from Words and Gestures (circles) or Words and Sentences (triangles); two of these points are enlarged for illustration. To calculate months-difference, we subtract the child's chronological age from their expected age (based on vocabulary). In this visualization, months-difference is the x-axis distance between the point and the curve (negative values right of curve, positive are left).

Applying this approach to each child, we observe wide variability; vocabulary differences for blind children range from 11 months ahead to 44.50 months behind; see Figure 7. A Wilcoxon 1-sample test on the data reveals that blind children's vocabulary difference significantly differed from 0 (0 would indicate no difference in vocabulary distribution of blind children from the 50th percentile of sighted children). Blind children had a mean vocabulary delay of 7.20 months (SD: 10). That said, 18.60% of our sample was ahead of the sighted 50th percentile norm. That is, rather than all of the blind children being behind the sighted 50th percentile (as would be the case if missing vision led to a pervasive, consistent delay in early word production), or blind children being indistinguishable from sighted peers in vocabulary size (which would have been manifest as roughly 50% of blind children with delayed and 50% with advanced vocabulary) we see an intermediary effect: roughly half a year delay on average, with about 20% of the sample showing a vocabulary advantage over the average for sighted peers.

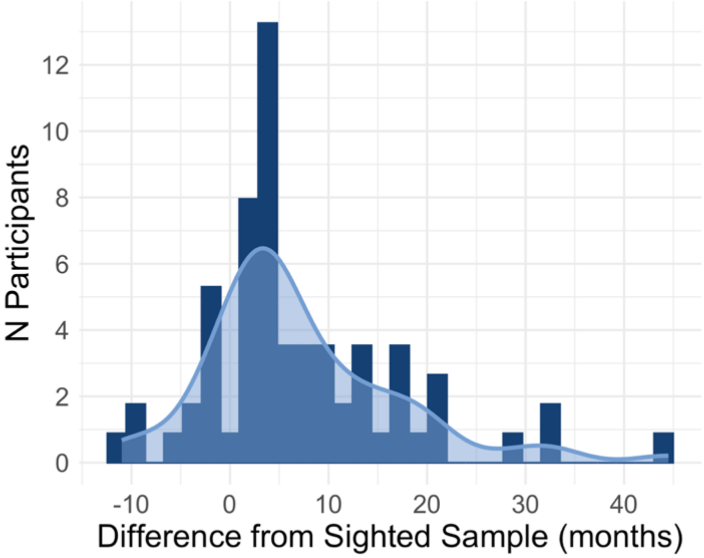

Figure 7: Histogram with overlaid density plot of blind sample's vocabulary difference relative to Wordbank norms. Positive values indicate delay, while negative values represent scores that are ahead of the 50th percentile curve from sighted participants.

3.3.2.1 Exploring Variability

To better understand the wide range of vocabulary outcomes, we next divided our blind sample along several child-level characteristics and compared the distribution of vocabulary differences via Wilcoxon tests; see Figure 8.

Splitting the sample by gender (N_{male}=21, N_{female}=17), we do not observe significant gender differences ($\text{Mean}_{\text{male}}$ delay = 8.27 months vs. $\text{Mean}_{\text{female}}$ delay = 6.64 months; W = 145.50, p = .656). We also did not observe differences based on severity of vision impairment within the severe-to-profound range of vision loss in our sample: children with severe vision impairment (some light perception; N_{severe}=26; $\text{Mean}_{\text{severe}}$ delay = 5.07 months) had a similar size vocabulary delay to children with profound vision impairment (no light perception, N_{profound}=11; $\text{Mean}_{\text{profound}}$ delay =12.44 months; W = 573.50, p = .119). Lastly, we divided by etiology and found no significant difference (W = 527, p = .287): central nervous system diagnoses (optic nerve hypoplasia or CVI; N_{central}=13; $\text{Mean}_{\text{central}}$ delay =12.07 months) vs. peripheral diagnoses ($N_{\text{peripheral}}$=18; $\text{Mean}_{\text{peripheral}}$ delay =3.92 months). We note that there was no particular selection for these dimensions within our eligibility criteria, and thus some of these comparisons are on numerically unbalanced samples.

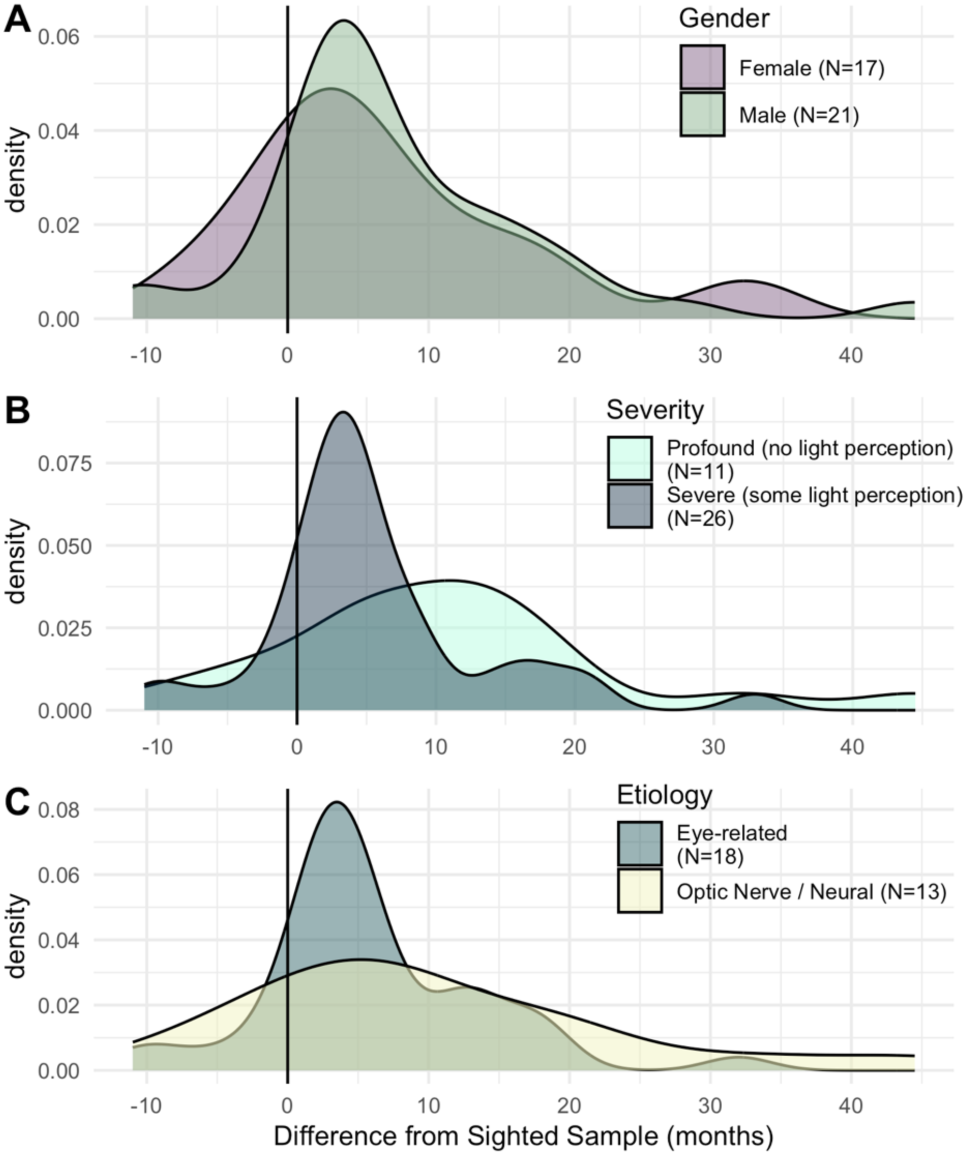

Figure 8: Density plot dividing the sample by gender (A), severity (B), and etiology (C).

3.3.2.2 Does the delay lessen across age?

We next measured whether the delay in vocabulary stayed constant across age. We conducted a linear mixed effect model with a fixed effect of age and a random effect of participant, given that for 14 participants, we have longitudinal administrations of the CDI.

If delay were constant, we would not expect it to change as children age. Instead, we found a significant effect of age, such that for each month increase in age, vocabulary delay increased by 2.07 weeks (F(1) = 38.72, *p* < .001); see Figure 9.

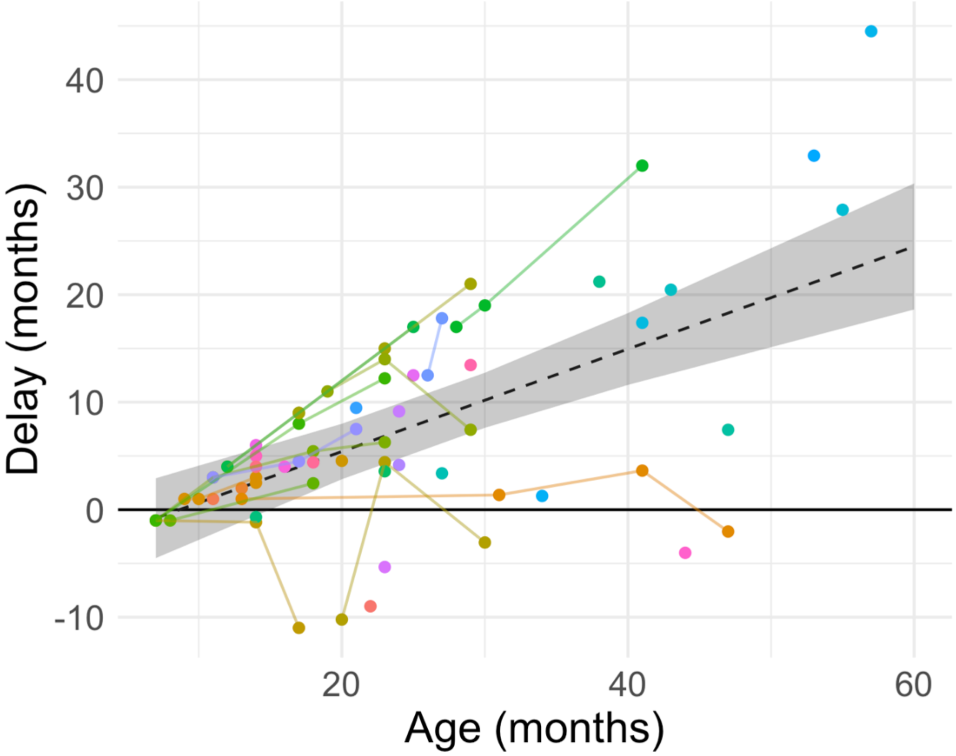

Figure 9: Vocabulary delay in blind children plotted as a function of age. Raw data are plotted in color. Each dot represents one CDI administration, with lines connecting datapoints from the same participant. Black dashed line represents the model estimate with ***standard error: Vocabulary Delay ~ Age + (1|Participant).***

3.3.3 Do blind children and sighted children have a similar vocabulary composition?

We next investigated the composition of blind children's early words. Given the disparities between the vocabulary production of blind vs. sighted children, we compared blind participants to a vocabulary-size-matched group of sighted children from Wordbank. We matched each blind child in our sample to a unique sighted participant from Wordbank. Sighted matches were selected to have the same number of words produced on the same form (WG vs. WS) and to be as close as possible in age to the blind child; beyond this matching they were selected at random. Consequently, our samples for the vocabulary composition analysis are equivalent in vocabulary production but differ slightly in age (sighted sample on average 4.70 months younger, *p* = .238 by Wilcoxon test); see Figure 10.

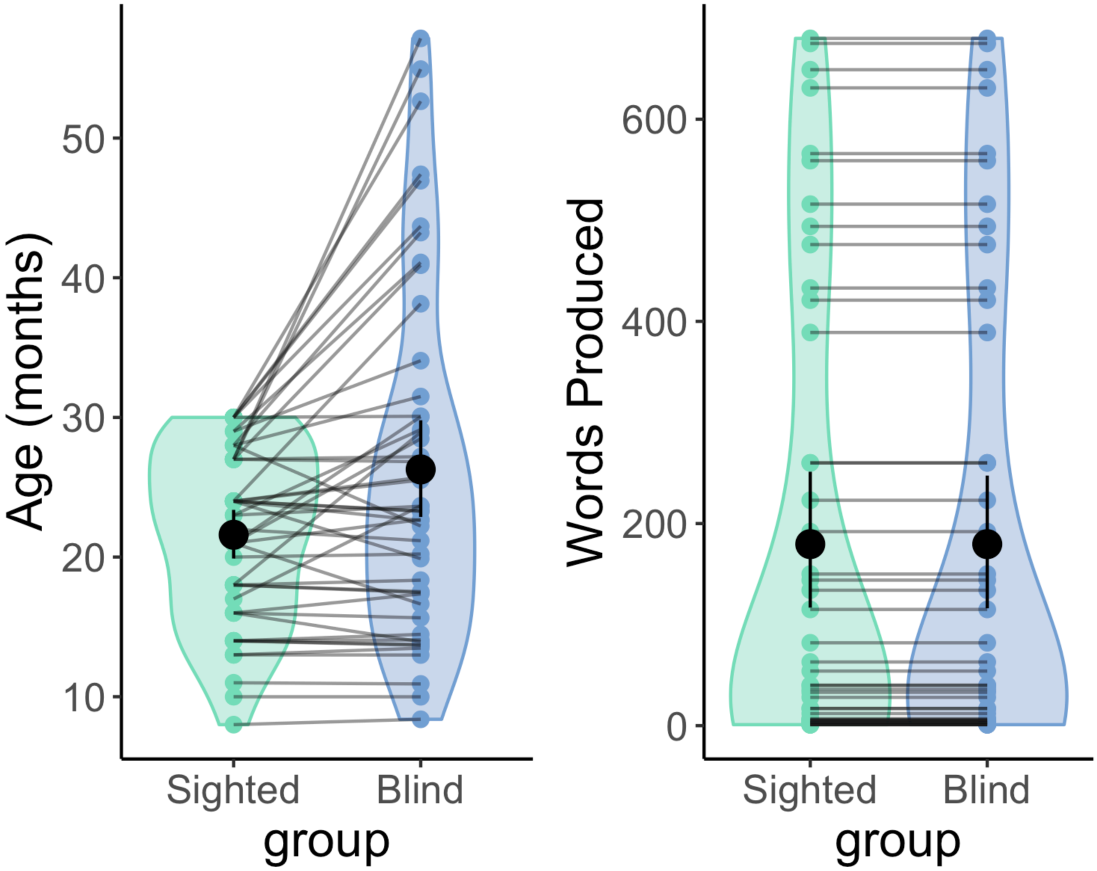

Figure 10: Violin plots for age (left) and vocabulary size (right) for blind participants and their vocabulary size matched sighted peers, from Wordbank. Each dot represents one participant. Given that participants are matched exactly on vocabulary, the vocabulary scores on the right panel are identical for blind and sighted participants.

We then compared the words that blind and sighted children with equivalent vocabulary size produced. Children producing 0 words were excluded from this analysis (N=3). We compared vocabularies along six dimensions: word length, part of speech, semantic category, concreteness, child-body-object interaction rating (interactiveness), and perceptual modality, operationalized below.

Word length was computed as number of syllables in each word. **Part of speech** adjectives, adverbs, function words, interjections, nouns, onomatopoeia, and verbs) and **semantic category**[1] (action words, animals, body parts, clothing, connecting words, descriptive words, food and drink, furniture and rooms, games and routines, helping verbs, household, locations, outside, people, places, pronouns, quantifiers, question words, sounds, time words, toys, and vehicles) subdivisions were taken from the categories on the CDI. For **concreteness**, we used the Brysbaert Concreteness ratings (Brysbaert et al., 2014), which asked sighted adult participants to rate words from 1 (Abstract - language based) to 5 (Concrete - experience based); 30 words were excluded from this analysis due to not having a concreteness rating. **Interactiveness** ratings were taken from the child-body-object interactiveness ratings from the Child-Body-Object Interaction ratings (Muraki et al., 2022). These are 1-7 ratings by parents of school-aged children of how easily children can physically interact with each of the words. 30 words were excluded from this analysis due to

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[1] Not all categories from Words and Sentences appear on Words and Gestures. Additionally, some of the "semantic categories" could also be considered parts of speech. The word-level breakdown of each of these categories can be found on our OSF page.

not having a rating. Lastly, **perceptual modality** was determined by the Lancaster Sensorimotor Norms (Lynott et al., 2020), taken from a large sample of sighted adults, who were asked to rate: "To what extent do you experience WORD by [hearing, smelling, tasting, seeing, etc.]?". Each word was rated 0-5 for each modality, and the modality which received the highest rating is used here for the perceptual modality of the word.

To compare words across each of these dimensions, we used profile analyses and Wilcoxon tests, depending on the type of variable. For semantic category, perceptual modality, and part of speech, we compared counts of each word type across groups using profile analysis (Bulut & Desjardins, 2020). For concreteness and word length, we ran Wilcoxon tests. Given that we conducted multiple comparisons (five total, one per dimension), the Bonferroni-corrected threshold for significance is 0.0083.

None of the comparisons reached the threshold for significance. Blind and sighted children's early vocabularies did not significantly differ in word length (W =863.50, Z = -1.93, p = .054), part of speech (F = 1.67, p = .143), semantic category (F = 1.93, p =.028), concreteness (W =510.50, Z = -1.88, p = .061), interactiveness (W =700.50, Z = -0.17, p = .867), or perceptual modality (F = 2.18, p = .067). See Figure 11 for vocabulary comparisons. Descriptively, both blind and sighted children's words tended to be short (Means: 1.46 and 1.53 syllables, respectively) and highly concrete (Means: 4.12 and 4.09 out of 5, respectively). The words that blind and sighted children produced tended to be rated as easy for children to interact with (Means: 5.50 and 5.60 out of 7, respectively). In both groups, nouns were the most common part of speech, and visual words comprised the overwhelming majority of children's early vocabulary.

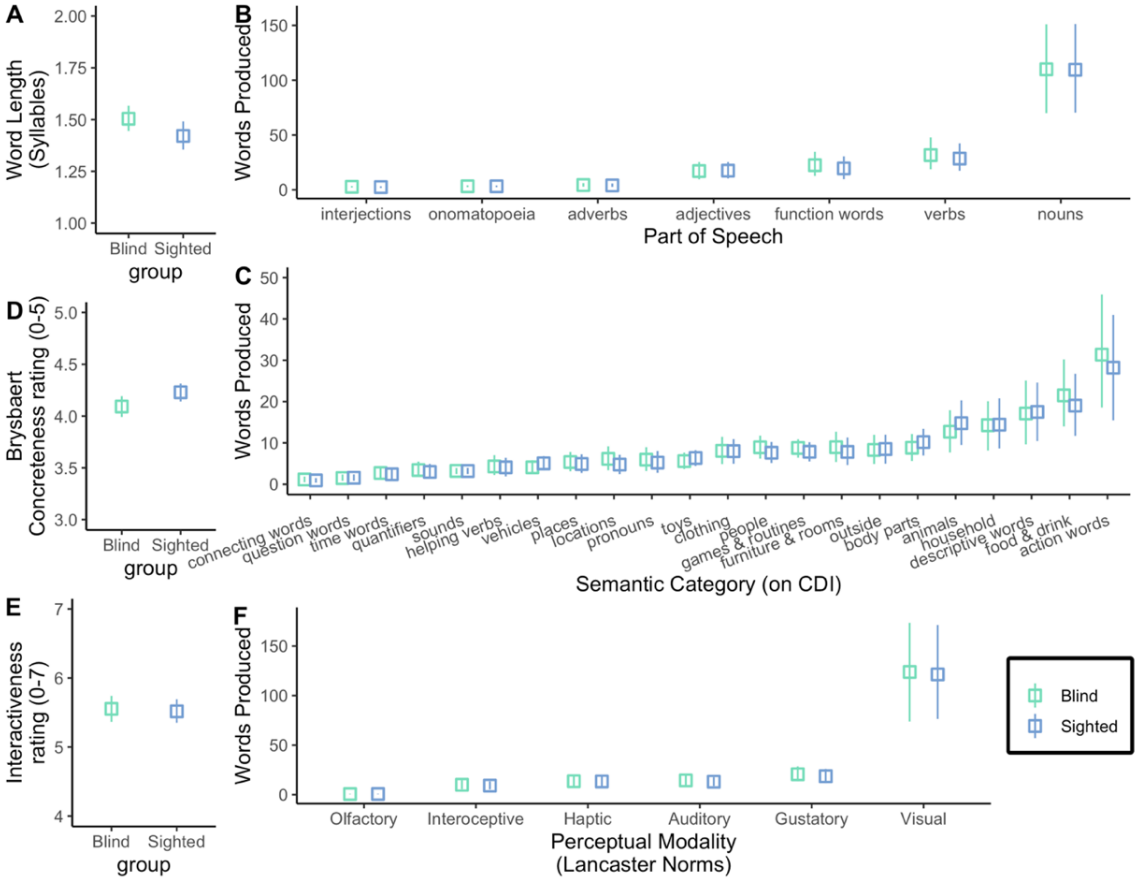

Figure 11: Comparisons of blind and sighted children's vocabulary across 6 dimensions. *Whiskers represent 95% CIs around the mean. A: Mean length (syllables) for sighted vs. blind participants. B: Mean N of words produced by blind and sighted children from each part of speech on CDI. C: Mean N of words produced by blind and sighted children from each semantic category on CDI. D: Mean concreteness rating 1 (abstract) – 5 (concrete) for sighted vs. blind participants. E: Mean child-body-object interaction rating 1 (not interactive) – 7 (highly interactive) for sighted vs. blind participants. F: Mean N of words produced by blind and sighted children for each perceptual modality (modality with highest perceptual rating on Lancaster Sensorimotor Norms). Note the truncated y axes for D and E.*

3.3.4. How do perceptual characteristics of words affect learnability?

On one hand, it was somewhat surprising to find such striking parallels in blind and sighted children's vocabulary, particularly the dominance of "visual" words, given that blind children lack visual access to the words' referents. Notably, prior work e.g. Landau & Gleitman (1985) suggests their blind subject Kelli also produced highly visual words, though, word modality distributions over the vocabulary was not something they explored. More germanely, it's worth noting that words the Lancaster Sensorimotor norms classify as visual are often perceptible through other modalities. For example, while "playground" is classified as a visual word on the Lancaster Sensorimotor Norms many of these words may be perceptible through other modalities. For example, while "playground" is classified as a visual word on these norms, playgrounds can also be experienced through touch, sound, smell, or even taste. This raises the possibility that although blind and sighted children's vocabularies contain similar amounts of visual words, the visual words that blind children produce may be qualitatively different from the visual words that sighted children produce. To explore this, we next compared blind and sighted children's likelihood of producing visual words (i.e., words whose highest perceptual ratings were visual) and non-visual words (i.e., words whose highest perceptual ratings were auditory, tactile, olfactory, interoceptive, or gustatory), based on the perceptual strength of each word and its perceptual exclusivity. To increase power for this more fine-grained analysis, we include all CDI administrations, rather than just the CDI from the oldest timepoint when multiple timepoints per child were available. Words that did not appear on a child's instrument (e.g., lawnmower does not appear on Words and Gestures) were excluded for those children.

To do this, we constructed two logistic mixed effect models that predicted the log likelihood of a word being produced as a function of the three way interaction between the word's perceptual modality (visual or non-visual)[2], group (blind or sighted), and either the word's perceptual strength (highest perceptual strength rating across all modalities, rated 1-5) or the word's perceptual exclusivity (expressed as a proportion from 0-1 calculated as the range of the ratings of all modalities divided by the sum of the ratings of all modalities. 0 = experienced equally in all modalities, 1 = experienced exclusively through a single modality); model formulae are below. Each model also included a random effect of child due to the multiple measures within some participants, as well as a random effect for word given that there is an observation for each word for each participant, and the likelihood of word-level variance being non-random (though not of interest for the present analysis). Thus, we fit two models as follows:

Perceptual Strength Model: $Word\ Production \sim$

$Perceptual\ Strength * Perceptual\ Modality * Group + (1 \mid Participant) + (1 \mid Word)$

Perceptual Exclusivity Model: $Word\ Production \sim$

$Perceptual\ Exclusivity * Perceptual\ Modality * Group + (1 \mid Participant) + (1 \mid Word)$

For the perceptual strength model (Table 10), we found a significant main effect of perceptual strength ($\beta = 0.92$, $p < .001$). Overall, the groups did not differ in likelihood of producing words ($\beta = 0.34$, $p = .722$), and the effect of perceptual strength did not differ by group (β = 0.05, p = .475) or by modality (β = -0.33, p = .598). This pattern of main effects was qualified by a significant interaction between group and modality, such that blind children were significantly less likely to produce visual words than non-visual words (β = 1.57, $p < .001$). Finally, there was a significant three-way interaction between modality, perceptual strength, and group, such that for sighted children, there was a similar effect of perceptual strength for visual and non-visual words. For blind children however, the effect of perceptual strength was much stronger for non-visual words than visual words (β = -0.49, $p < .001$). See Figure 12.

For the perceptual exclusivity model (Table 11) we again found that the groups did not differ in overall likelihood of producing words (β = 0.22, p = .811). The main effect of perceptual exclusivity was not significant (β = 0.93, p = .351), and did not differ by group (β = 0.71, p = .129). Here too, this pattern of main effects was qualified by a significant interaction between group and modality, such that blind children were significantly less likely to produce visual words (β = 0.85, $p < .001$). Finally, we again observed a three-way interaction, here between modality, perceptual exclusivity, and group, such that for the sighted group, words that were more unimodal were more likely to be produced for both visual and non-visual words. By contrast, for the blind group, non-visual words that were more unimodal were more likely to be produced, but visual words that were more unimodal were *less* likely to be produced (β = -2.98, $p < .001$).

Table 10: Logistic regression estimates for the perceptual strength model (see formula in main text). Reference level for Modality is non-visual, and reference level for Group is sighted.

Variable	**Beta [95% CI]**	***p* value**
(Intercept)	-6.35 [-7.91, -4.79]	< .001***
Modality (visual)	-0.33 [-1.57, 0.90]	.598
Perceptual Strength	0.92 [0.69, 1.15]	< .001***
Group (blind)	0.34 [-1.52, 2.20]	.722
Modality (visual) × Perceptual Strength	0.02 [-0.30, 0.34]	.891
Modality (visual) × Group (blind)	1.57 [0.91, 2.24]	< .001***
Perceptual Strength × Group (blind)	0.05 [-0.08, 0.17]	.475
Modality (visual) × Perceptual Strength × Group (blind)	-0.49 [-0.66, -0.32]	< .001***

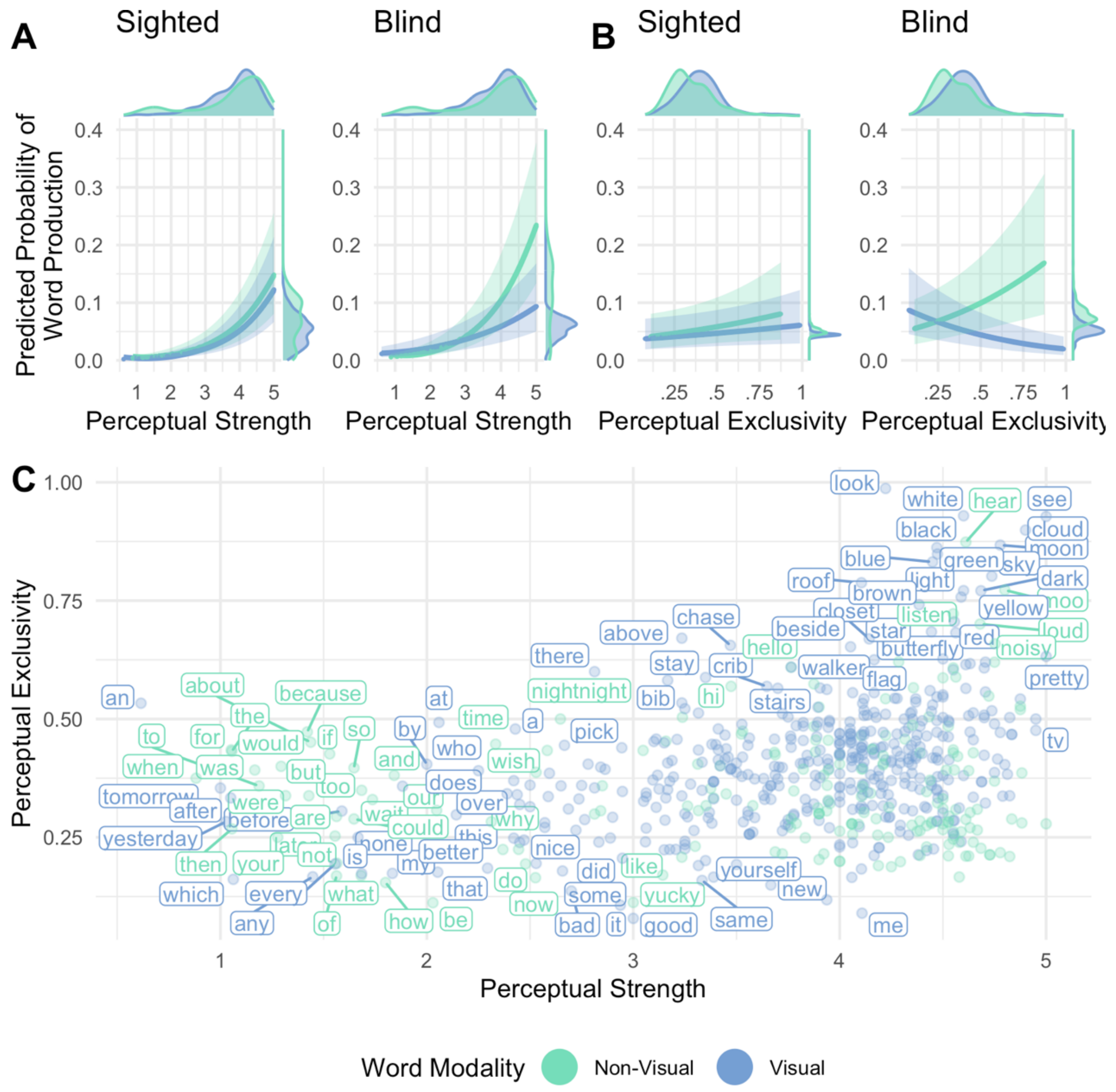

Figure 12: Visualization of *Visualization of the significant 3-way interaction between A Modality (visual/non- visual), Perceptual Strength (0-5), and Group (blind/sighted) and B Modality, Perceptual Exclusivity (0-1), and Group in predicting probability of word production (see text for model details). Y-axis shows the model-predicted probability of word production, with 95% confidence interval; distribution of predicted probability (of individual words) shown in margins. The x-axis shows perceptual property (perceptual strength in A, perceptual exclusivity in B); distribution of words' varying ratings shown in margins. C: Perceptual properties of visual and non-visual on the CDI – perceptual strength on the x-axis and perceptual exclusivity on the y-axis. Some individual words are labeled for illustrative purposes.*

Table 11: Logistic regression estimates for the perceptual exclusivity model (see formula in main text). Reference level for Modality is non-visual, and reference level for Group is sighted.

Variable	**Beta [95% CI]**	***p* value**
(Intercept)	-3.25 [-4.71, -1.78]	< .001***
Modality (visual)	-0.04 [-0.94, 0.85]	.930
Perceptual Exclusivity	0.93 [-1.02, 2.88]	.351
Group (blind)	0.22 [-1.60, 2.05]	.811
Modality (visual) × Perceptual Exclusivity	-0.37 [-2.65, 1.92]	.751
Modality (visual) × Group (blind)	0.85 [0.42, 1.28]	< .001***
Perceptual Exclusivity × Group (blind)	0.71 [-0.21, 1.63]	.129
Modality (visual) × Perceptual Exclusivity × Group (blind)	-2.98 [-4.08, -1.89]	< .001***

3.4 Discussion

This study compared the early vocabularies of blind and sighted children to better understand the influence of vision on acquiring a lexicon. We found that while blind children in our sample showed vocabulary delays, there were remarkable similarities between the vocabulary composition of blind and sighted children. These results suggest that visual perception facilitates word learning, but does not determine the content of early vocabulary. We further found that the likelihood of word production was predicted by children's access to words through one vs. multiple modalities.

While the absence of vision does seem to result in vocabulary delays for most children (in our sample, roughly half a year delay on average, with ~20% of blind children ahead of the 50th percentile of sighted children), the exact mechanism by which vision influences vocabulary growth remains unclear. Referential transparency alone seems unlikely: when blind children learn words, they learn a similar number of "visual" words as sighted children. Future work measuring social, motor, and cognitive development alongside vocabulary in blind children may illuminate skills that support word learning. Differences in language input to blind children could also explain the wide variability in language outcomes. By hypothesis, associations between language input and vocabulary development might even be stronger in blind children, given that language may be blind children's source of "visual" information about the world (Campbell & Bergelson, 2022b).

While we only included participants without diagnosed cognitive or developmental delays, some participants had vocabulary sizes that fell on the extremes of the distribution; this might indicate undiagnosed cognitive challenges. Given that many early childhood cognitive assessments are not accessible for children with visual impairments (e.g., WPPSI-IV, DAS-II; Bayley), monitoring productive vocabulary growth could provide insight into blind children's cognitive development.

While evidence from blind adults and older children suggests that language skills improve (Landau & Gleitman, 1985; Loiotile et al., 2020; Röder et al., 2003), we did not see evidence that vocabulary delays lessen in our age group. In fact, older children in our sample have larger delays. This could be a floor effect: the *possible* size of the delay increases over time, such that 12-month-olds cannot be 18 months delayed, but 30-month-olds can. That said, if blind children, after an initial delay, learn words at the same rate as the sighted peers we would expect to see a constant delay; we saw an increasing one. This bumps the question downstream: if blind children eventually catch up to sighted peers, when and how does this happen?

One possibility is that blind children initially struggle with word learning. The first words in blind children's vocabulary might be hard-earned. Vision might provide an easier or more efficient way for sighted children to connect referents to objects in their environment. Perhaps after blind children build their initial lexicon, they can leverage linguistic structure more effectively, through processes like syntactic bootstrapping (Babineau et al., 2021; Gleitman, 1990). Evaluating this hypothesis awaits further work.

Turning to vocabulary *content*, blind and sighted children's lexicons were overwhelmingly similar: they were characterized by noun dominance, short, concrete, physically interactive words, and common topics (Frank et al., 2021). Summarizing, blind children learn largely the same set of early words as sighted children. And while we found that the vocabularies of both sighted and blind children were dominated by "visual" words, the bulk of the words on the CDI (Winter et al., 2018) are rated by sighted adults as primarily associated with visual experience; in ongoing work, we are creating new norms from blind adults to further explore how these ratings may vary by sensory experience.

That said, we found that learnability of visual words differed based on words' finer-grained perceptual properties. For blind children, higher perceptual exclusivity (less multimodality) predicted *lower* likelihood of production for visual words (but not non-visual words). For sighted children, perceptual exclusivity did not affect production of either word type. Relatedly, for blind children, higher perceptual strength ratings predicted greater likelihood of word production for non-visual words, but lacked this strong relationship for visual words. Contrastingly, in sighted children, higher perceptual strength predicted greater production likelihood of all words. These exploratory findings suggest that visual words like *light* (highly visual and unidimensional), are less likely to be produced by blind children relative to "visual" words that can be perceived through other modalities (e.g. *table*).

As a relatively large-scale study of language development in young blind children, these results are clinically relevant. Chiefly, blind children are at risk of language delays and may benefit from early intervention communication support. While initial delays may resolve (Brambring, 2007), providing young blind children and their caregivers with tools to communicate better may reduce children's frustration in toddlerhood (Manning et al., 2019).

It is worth noting that by design, this study does not capture the full linguistic or diagnostic variability of the blind population. We constrained the sample to young, monolingual, English-speaking blind children with no more than minimal light perception and no cognitive, developmental, or auditory diagnoses. In reality, the population of children with visual impairments encompasses a broad range of perceptual abilities, language backgrounds, and life experiences. Future work could investigate whether these results generalize to more diverse samples or whether variability in language background or diagnosis contributes to differences in vocabulary outcomes.

Many questions remain regarding how vision interacts with children's social and cognitive skills to form the lexicon. What do blind children's early representations of visual words entail? Is the lexicon organized similarly? How do blind children extract visual information from language input to learn more about both language and their environment? Future work on language development in blind children capturing a more holistic view of blind children's skills and environments is needed to further our understand of how perception and language input interact to support children's learning.

4. Early Production of Imperceptible Words by Infants and Toddlers Born Deaf or Blind

Does being able to see blue or hear a cat's meow make it easier to learn the words "blue" or "meow"? Children rely on a range of experiences to build emerging word knowledge, using their early sensory, perceptual, motor, and linguistic experiences to inform what they know about words (Campbell & Bergelson, 2022b; Glenberg & Gallese, 2012; Perniss & Vigliocco, 2014; Smith et al., 2011). More specifically, visual experience with colors, auditory experience with sounds, and linguistic experience with abstract concepts like pretend might facilitate word learning for visual, auditory, and abstract concepts, respectively. While no one has direct sensory access to abstract concepts, children born blind or deaf also lack access to the range of sensory experiences that are a given for the typically hearing and sighted majority. Moreover, children born deaf often experience delayed access to language input, as the majority of deaf children are born to hearing parents who do not know a sign language at the time of birth (Mitchell & Karchmer, 2004, 2005). In what follows, we first consider how sensory experience may be linked to word learning in theory, how this ties to existing empirical data on sighted, hearing, blind, and deaf adults, and how this extends to initial learning in early infancy. Against this background, we ask how access to different sources of meaning (i.e., perceptual and linguistic information) shapes the early words children say.

Theories of embodied cognition posit that sensorimotor experience is a requisite part of how humans acquire knowledge and process information (Allport, 1985;

Barsalou, 1999). Lending potential support to this, experiments with adults suggest that some sensorimotor simulation occurs during word processing (Davis et al., 2020; Trumpp et al., 2013; Yee et al., 2013). Under the strongest version of these hypotheses, language processing intrinsically involves the activation of prior sensorimotor experiences associated with underlying concepts (Glenberg & Gallese, 2012; Khatin-Zadeh et al., 2021; Mahon & Caramazza, 2008).

According to these theories, the easier it is to link a word (label) to a sensorimotor experience (referent), the easier that word should be to learn. There are at least two ways to conceive of the ease with which a word can be linked with a referent in word learning as a function of abstractness. First, abstractness can be investigated through the lens of iconicity: to what extent does the physical form of the word correspond to its meaning? Words themselves serve as abstractions from the physical: calling a train "train" requires more abstraction than calling it a "choo-choo". Indeed, in both spoken and signed languages, words that more closely resemble their referents (i.e., are more iconic) tend to be learned earlier than words that are more abstract or arbitrary (Caselli & Pyers, 2020; Perlman et al., 2018; Perry et al., 2015). A second way to think about abstractness is as imperceptibility: some words do not correspond with perceptible referents, e.g. "time", or "think" (Connell & Lynott, 2012; Iliev & Axelrod, 2017; Reed & Dick, 1968; Schwanenflugel & Shoben, 1983). Concomitantly, words that refer to objects children can physically perceive or interact with tend to be learned earlier (Muraki et al., 2022; Thill & Twomey, 2016). While abstractness as iconicity and im- perceptibility are intertwined notions, here we query the latter: how does experiencing a referent through the senses influence its likelihood of entering the early productive vocabulary?

If, as embodied cognition supposes, sensorimotor experience is a critical part of acquiring and processing concrete words, we would expect blind individuals' knowledge of visual words and deaf individuals' knowledge of auditory words to be compromised[2]. However, evidence from these populations suggests otherwise. Blind and deaf adults possess rich semantic knowledge of perceptual words from inaccessible modalities (Campbell & Bergelson, 2022b). For example, blind and sighted adult participants produce virtually indistinguishable semantic similarity judgments for sets of perceptual words, including visual words (Bedny et al., 2019), and blind children and adults demonstrate context-appropriate usage of words like "look", "see", and color words both literally (Landau & Gleitman, 1985) and figuratively (Minervino et al., 2018). Blind individuals don't seem to simply encode visual words as abstract words (disconnected from perceptual experience); rather, blind adults exhibit differentiated neural responses for concepts that are, for them, imperceptible, perceptible, and abstract (Striem-Amit et al., 2018). Similar results have been found in deaf individuals. Recent work presented native deaf ASL signers with sound stimuli via tactile vibrations (Emmorey et al., in press). Participants were asked to describe the sounds in ASL. The

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[2] Throughout, we use "{visual, auditory, abstract} words" as shorthand to refer to words with visual, auditory, and abstract referents.

Deaf[3] signers provided signed descriptions for 95% of the sounds–only ~5% received an "I don't know" response. These descriptions included conventionalized signs for auditory properties (e.g., LOUD[4]), naming the source of the sound, or using handshapes and movement to visually depict the sound. Relatedly, many sign languages worldwide have signs with highly auditory meanings (Hilzensauer & Krammer, n.d.). In both blind and deaf populations, therefore, a lack of experience in a given sensory domain does not inhibit acquiring detailed and readily relayed semantic knowledge in that domain, raising doubt about whether sensory experiences are necessary for acquiring sensory word concepts.

An alternative hypothesis to strong versions of embodied cognition is that semantic knowledge of imperceptible modalities can be derived from language in addition to direct sensory experience (Landau & Gleitman, 1985; Lewis et al., 2019; Saysani et al., 2021; van Paridon et al., 2021). Evidence for this includes the work cited above, as well as work showing blind individuals' semantic associations for color closely resemble those of sighted individuals (Saysani et al., 2021), with word ratings for both groups predicted by the contexts in which color words occur (i.e. words' distributional semantics in natural language) (van Paridon et al., 2021).

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[3] We use *d*eaf to refer to the auditory status, and *D*eaf to refer to the subset of that community who affiliates with Deaf culture and uses sign language.

[4] Glosses, indicated here as small caps, are a writing convention in which ASL is transcribed in ASL word order with English labels of signs, along with any signed structural markers.

In related work testing blind and sighted adults on animal-to-color matching, both groups' performance too was tied to semantic representations derived from natural language (and more strongly so for blind than sighted adults; Lewis et al., 2019). This further underscores a plausible role for the distributional structure of language in driving semantic representations of perceptual referents (Lewis et al., 2019). Summarizing, blind and deaf adults' ability to learn imperceptible words suggests they have acquired sufficient linguistic competence to abstract away from direct experience (Landau & Gleitman, 1985). How might this develop in early childhood?

By toddlerhood, sensory systems are relatively mature (Bremner et al., 2012; Leat et al., 2009; Mohan & Dobson, 2000; Schmidt & Beauchamp, 1992; Wild et al., 2017), while language abilities are still rapidly changing. Children can glean information about words' meanings from perceptual input, linguistic context, and social cues (Babineau et al., 2022; Bergelson, 2020; Marchman, 2021). As children are exposed to language across perceptual and linguistic contexts, word representations are refined (Meylan & Bergelson, 2022).

But perceptual input is variably informative for different word meanings, i.e. more so for concrete words, less for abstract ones. For abstract words, children must (by definition) rely more on sources like linguistic context (Schwanenflugel & Shoben, 1983) and social cues (Borghi & Binkofski, 2014; Ponari et al., 2020). Thus, words with more perceptually-available referents may be easiest for the youngest language learners (Fourtassi et al., 2019; Schwanenflugel & Shoben, 1983), with children's abilities to make inferences about abstract word meanings growing as lexical, syntactic, and social understanding increase over developmental time (Bellagamba et al., 2022).

This pattern is reflected in the trajectory of children's early vocabularies; concrete words tend to be learned before abstract words (Bellagamba et al., 2022; Bergelson & Swingley, 2013; Ponari et al., 2017). Seeing, touching, and tasting objects provides rich perceptual information towards developing concept knowledge (Slone et al., 2019; Suarez-Rivera et al., 2022; Yu & Smith, 2012), and words with referents that children can manipulate tend to be learned earlier (Muraki et al., 2022; Thill & Twomey, 2016). In the absence of direct perceptual experience with a word's referent (which is the case for abstract words for all children or for visual/auditory words for blind/deaf children, respectively), a central avenue for uncovering that meaning is through linguistic structure, including morphosyntactic cues (Gleitman, 1990) and distributional ones (Vigliocco et al., 2009). The ability to extract this semantic information improves as children develop linguistic competence (Babineau et al., 2022; Bohn et al., 2021).

However, delays in access to structured language input may impede this process. The vast majority of deaf children are born into hearing families where parents' only native language is a spoken one (Mitchell & Karchmer, 2004, 2005). In this scenario, parents' fluent spoken language input is partially or fully inaccessible to deaf children without use of a hearing aid or cochlear implant, and if they opt to provide a fully accessible sign language, they must learn it alongside their child (Mitchell & Karchmer, 2005). Despite improvements in hearing screenings and auditory technology (Carlyon &

Goehring, 2021; Carr & Kihm, 2022; Harrison et al., 2003; Subbiah et al., 2018), even infants identified with hearing loss at birth tend to not receive hearing aids or cochlear implants until months later (Campbell & Bergelson, 2022a; Marnane & Ching, 2015), and these devices do not perfectly restore auditory access (Dettman et al., 2021; Zimmerman-Phillips et al., 2000). In the sign language case, children's initial input is non-native, and not initially fluent (Mitchell & Karchmer, 2005). Regardless of whether it is in the spoken or signed modality, recent evidence suggests earlier access (e.g., before 6 months) leads to better language outcomes (Caselli et al., 2021; Hall et al., 2017; Svirsky et al., 2004; Yoshinaga-Itano et al., 2018).

Given the potential importance of linguistic knowledge for imperceptible words in particular, if vocabulary development is delayed (e.g., due to lack of accessible language input), abstract and imperceptible words may be disproportionately delayed (Vigliocco et al., 2018). Since early vocabularies are largely composed of highly sensory words, there could be a cyclical effect wherein the lack of foundational linguistic knowledge delays the acquisition of the early vocabulary on which infants can build further linguistic knowledge (Babineau et al., 2021; Gutman et al., 2015). The ability to extract semantic information from linguistic structure may thus be disrupted for young blind or deaf learners.

Taken together, the evidence suggests that sensory and linguistic input helps children build rich representations of their early world. For young children born blind or deaf, however, it remains unclear how inaccessible input may influence early learning of perceptible vs. imperceptible words. Our question is not whether individuals who are blind or deaf can learn imperceptible and abstract words–indubitably they can (Bedny et al., 2019; Emmorey et al., in press; Landau & Gleitman, 1985; Vigliocco et al., 2018). Instead, we examine whether imperceptible and abstract words are uniquely more challenging to learn based on early perceptual and linguistic experience. Towards this aim, we assess the composition of the early productive vocabulary of blind children, deaf children, and children who experienced delayed language access (late exposure to English or ASL).

We address two central questions:

1. Does modality-specific perceptual experience facilitate word production? To answer this, we compare production of visual words by congenitally-blind or deaf children versus typically-sighted or hearing children.
2. Does early access to language input facilitate the acquisition of abstract words? To answer this, we compare abstract word production in a group of children first exposed to spoken English or to ASL in toddlerhood versus from birth.

4.2 The Present Study: Assessing Early Visual, Auditory, and Abstract Vocabulary.

Parents of all children completed the Communicative Development Inventory (CDI), (either American English Words & Sentences (Bates et al., 1994) or ASL CDI 2.0 (Caselli et al., 2020), as relevant), a parent vocabulary checklist that indicates whether children produce standardized set of several hundred words (Fenson et al., 1994). From this, we analyze a subset of highly visual, auditory, and abstract words (N = 30 words for spoken English; 26 for ASL; Table 17 and Figure 16). In each analysis, we control for children's chronological age and for lexical properties known to influence word production (frequency, phonological complexity, and iconicity; see Table 17 in Methods). For each of these analyses, we also match participants from one group (blind, deaf spoken English, and deaf late ASL) to two participants from the other group (sighted, typically-hearing, and deaf early ASL, based on the size of children's total productive vocabulary on the CDI (note that vocabulary size matching makes exact age-matching impossible); see Methods for matching details. Participant details are available in Table 16. By matching groups on vocabulary size, we can ask whether children with perceptual or language access differences are more or less likely to produce our words of interest relative to children who produce the same number of total words.

4.3 Analysis

Analyses were conducted in R, using the lme4, emmeans, and ggggeffects packages. Data and code for these analyses are available on OSF, as are full citations for all R libraries used. For each of three comparisons (blind/sighted, deaf spoken language/typically-hearing, or deaf early ASL/deaf late ASL), we construct a series of mixed effect logistic regression models predicting the probability of word production, given child characteristics (details in Table 16) and lexical properties (details in Table 17). Each model estimates the likelihood of word production based on age, each words' frequency (corpus-based for English or native speaker ratings for ASL), phonological complexity (syllables for English or phonological complexity score for ASL), and iconicity, main effects of group (blind/sighted, deaf spoken language/typically-hearing, or deaf early ASL/deaf late ASL) and word modality (abstract, auditory, or visual), and an interaction term between group and modality. This interaction was our primary effect of interest, as a significant interaction between group and modality would indicate that the likelihood of word production varies differentially across modality based on group membership. In all models, we also include a random effect for participant, to account for multiple observations (words) from each child.

4.3.1 Blind children and sighted peers

We first compare the two groups of children that differ in visual access but not auditory or language access: blind toddlers (N = 36, 13.90– 57.10 months, M: 31.88 (11.67)) and vocabulary-size-matched sighted matches (N = 72, 16.00–30.00 months, M: 23.58 (4.43)). Here, *auditory* is the reference level for Modality, as these groups do not differ in auditory access. Our model formula is: **Production ~ Age + Group**$_{\text{Blind vs. Sighted}}$ * **Modality**$_{\text{Abstract vs. Auditory vs. Visual}}$ **+ log(Frequency) + Syllables + Iconicity + (1|Participant)**. As expected, we find significant main effects of age, word frequency, word length, and iconicity: words were more likely to be produced by older children, and when they were more frequent, shorter, and more iconic. While overall, blind and sighted children were equally likely to produce words, we did find a significant main effect of modality such that across groups, abstract words are 50.4% less likely to be produced than auditory words. Most notably, we find a significant interaction between group and modality, such that sighted children are significantly more likely to produce visual words than blind children, but equally likely to produce auditory and abstract words. This effect on visual words was large: sighted children were 7.08 times more likely than blind children to produce this highly visual set of 10 words (Figure 13.A). See Table 12 for full model results.

Table 12: Model estimates for blind and sighted participants. In this model, sighted is the reference level for group, and auditory is the reference level for modality.

Variable	Beta (log odds)	Standard Errors	*p*
Age (months)	0.25	0.05	< .001
log(Frequency)	-0.04	0.05	.364
Syllables	-0.84	0.09	< .001
Iconicity	0.77	0.07	< .001
Modality (abstract)	-0.70	0.23	.002
Modality (visual)	-0.35	0.21	.100
Group (blind)	-1.19	0.81	.144
Modality(abstract):Group	-0.02	0.34	.947
Modality(visual):Group	-1.96	0.35	< .001

4.3.2 Deaf children learning spoken English and typically-hearing peers

We next compared children that differ in both auditory and language access (but not in visual access): Deaf children learning spoken language (N = 20, 20.00–49.00 months, M: 34.74 (10.06)) and their typically-hearing peers (N = 40, 17.00–30.00 months, M: 23.95 (4.34)). Here, *visual* is set as the reference level for Modality, as these groups do not differ in visual access. Our model formula is: **Production ~ Age + Group**$_{\text{Deaf Spoken Language vs. Typically-Hearing}}$ **+ Modality**$_{\text{Abstract vs. Auditory vs. Visual}}$ **+ log(Frequency) + Syllables + Iconicity + (1|Participant)**; see Table 13. Again, we find significant main effects of age, word frequency, word length, and iconicity: words were more likely to be produced by older children, and when they were more frequent, shorter, and more iconic. In this model, we found a significant main effect of group: across word modalities, typically-hearing children were 14.35 times more likely to produce a given word than deaf children learning spoken language. For the deaf spoken language group, but not the typically-hearing group, we found significant differences between word modalities. This interaction reveals that the difference between groups was greater for abstract words, relative to visual words: in this case typically-hearing children were 2.43 times more likely than their deaf peers to produce abstract words; see Figure 13.B. Full model results are described in Table 13.

Table 13: Model estimates for blind and sighted participants. In this model, hearing is the reference level for group, and visual is the reference level for modality.

Variable	Beta (log odds)	Standard Errors	*p*
Age (months)	0.29	0.05	< .001
log(Frequency)	-0.03	0.06	.555
Syllables	-0.90	0.12	< .001
Iconicity	0.93	0.08	< .001
Modality (abstract)	0.10	0.25	.696
Modality (auditory)	0.22	0.27	.413
Group (deaf)	-2.66	0.91	.006
Modality(abstract):Group	-0.89	0.42	.034
Modality(visual):Group	-0.11	0.38	.778

4.3.3 Deaf Children with Early ASL Access and Deaf Children with Late ASL Access

Lastly, we compare two groups of children learning ASL: one exposed to language from birth (Early ASL; N = 72; 9.00–56.00 months, M: 25.74 (9.01)) and one after a delay (Late ASL; N = 36; 12.00–59.00 months, M: 38.50 (13.05)). Here, the two groups differ in language access but not in visual or auditory access. As in the preceding analysis, visual is set as the reference level for Modality, given the groups' equivalent visual access; see Table 14. Our model formula is: **Production ~ Age + Group**$_{\textbf{Deaf Early ASL vs.}}$

$_{\text{Deaf Late ASL}}$ * **Modality**$_{\text{Abstract vs. Auditory vs. Visual}}$ **+ Frequency + Phonological Complexity + Iconicity + (1|Participant)**.

As in the other models, older children are more likely to produce a given word. Words that native signers rated as more frequent and more phonologically complex were more likely to be produced. We did not find significant differences between the early ASL and late ASL groups when looking at the words altogether. Across groups, visual signs were 4.79 times more likely to be produced than abstract signs and 6.39 times more likely to be produced than auditory signs. We did not find that these differences in production of different word modalities varied significantly by group. See Figure 13.C and Table 14.

Table 14: Model estimates for early ASL and late ASL participants. In this model, early ASL is the reference level for group, and visual is the reference level for modality.

Variable	Beta (log odds)	Standard Errors	*p*
Age (months)	0.10	0.02	< .001
log(Frequency)	0.36	0.09	< .001
Phonological Complexity	0.28	0.09	.002
Iconicity	-0.02	0.04	.634
Modality (abstract)	-1.57	0.21	< .001
Modality (auditory)	-1.86	0.29	< .001
Group (Late ASL)	-0.52	0.44	.239
Modality(abstract):Group	0.29	0.27	.294
Modality(visual):Group	-0.04	0.48	.935

4.3.4 Exploring the interaction between language access and perceptibility on early word production

While we found that children who received delayed access to spoken language were particularly less likely to produce abstract words (relative to visual words); children who received late access to ASL didn’t show an analogous effect. To try to better understand this discrepancy, we conducted an additional exploratory analysis designed to maximize the possibility of finding an effect of language access. To increase statistical power, we combined the groups from the second and third analysis into an early language input group (typically-hearing children and deaf children learning ASL; all have full language access from birth) and a late language input group (deaf children with cochlear implants learning spoken English and deaf children learning ASL at a delay); see Table 15). This gave us a larger sample size (N = 112 for Early Language Access, N = 56 for Late Language Access), while maintaining the vocabulary-size matching.

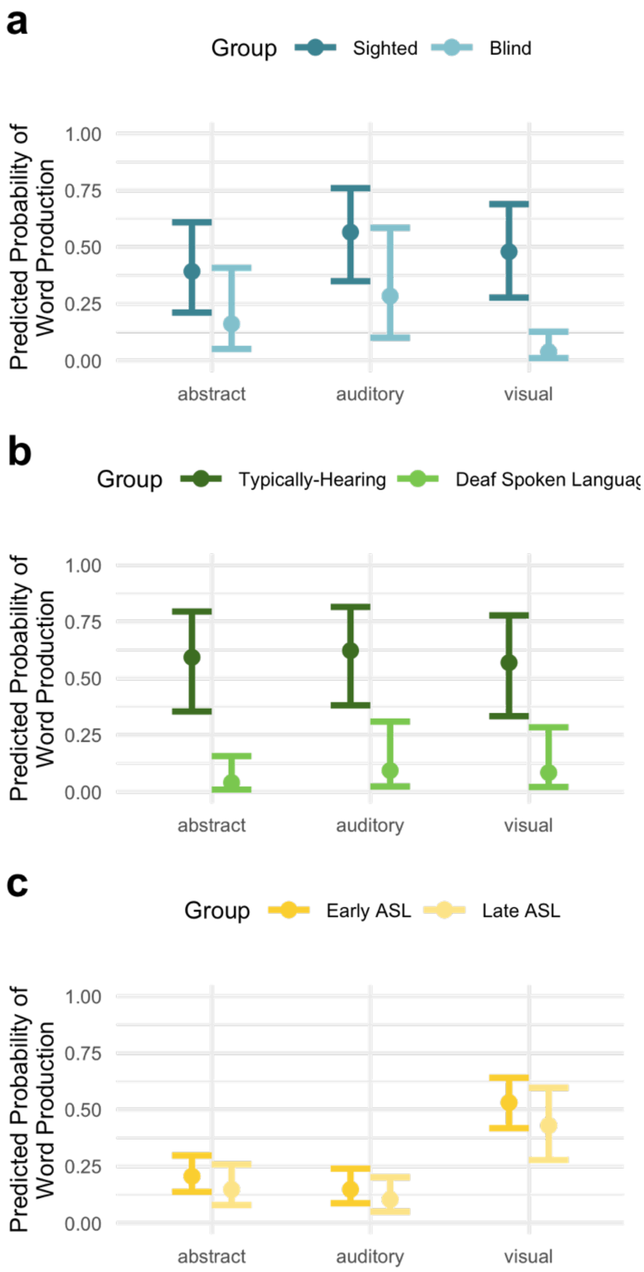

Figure 13: Predicted probabilities of word production by modality and group, controlling for age, frequency, phonological complexity, and iconicity; see text for model formulas. A. Blind and sighted participants. B. Deaf spoken language and typically-hearing participants. C. Deaf early ASL and Deaf late ASL participants. Whiskers represent confidence intervals around the mean. N.b., predicted probability values should not be compared across panels. Vocabulary size was not controlled for statistically, but rather controlled for within each analysis by matching groups on vocabulary size.

This analysis focuses on words that were equally perceptible or imperceptible to all children in this subsample (i.e., visual and abstract words). For these words, since the lexical properties differ across spoken English and ASL (log corpus-based frequency for English vs. Native speaker frequency ratings for ASL; syllable length for English vs. phonological complexity for ASL), we z-scored words' frequency, phonological complexity, and iconicity separately by language and then used these z-scored values as the lexical properties in the model. The larger sample size in this analysis allowed us to include a more complex random effects: in addition to the random effect of participant, we included a random effect for word, nested within language: **Production ~ Age + Frequency + Phonological Complexity + Iconicity + Language Timing * Modality (1|Participant) + (1|Language/Word)**; see Table 15.

Results were largely consistent with the previous analyses: for each month older, children were 20.6% more likely to produce words than younger children. We found kids that received early access to language input (i.e., before 6 months) were 6.42 times more likely to produce words, and visual words were 3.69 times more likely to be produced than abstract words. Critically, however, there was no significant interaction: early versus late access to language did not differentially affect the production of visual vs. abstract words; see Figure 14.

Table 15: Model estimates for early ASL and late ASL participants. In this model, early ASL is the reference level for group, and visual is the reference level for modality.

Variable	Beta (log odds)	Standard Errors	*p*
Age (months)	0.19	0.02	< .001
Frequency z-score	0.44	0.31	.152
Phon. Complexity z-score	0.02	0.21	.935
Iconicity z-score	0.06	0.17	.750
Modality (abstract)	-1.31	0.41	<.001
Modality (auditory)	-1.86	0.54	.001
Group (Late ASL)	-0.06	0.25	.814

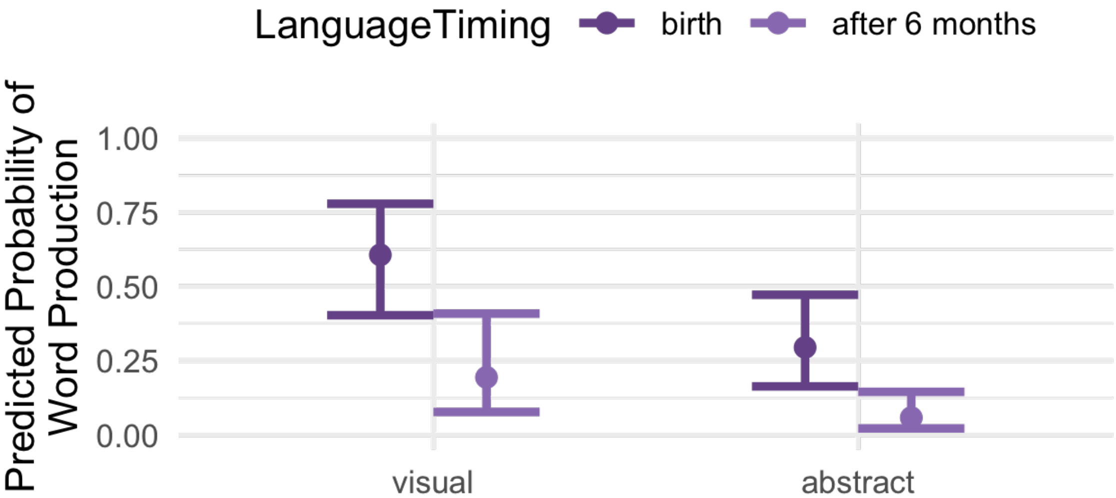

Figure 14: Predicted probabilities of word production by language timing and modality, controlling for age, frequency, phonological complexity, and iconicity.

4.4 Discussion

4.4.1 Perceptibility and Word Production

Across analyses, we find two key results. First, across our range of participants with varying visual, auditory, and linguistic access, children were less likely to produce words in imperceptible domains, relative to perceptible domains. This extends prior work about the acquisition of concrete vs. abstract words (Bellagamba et al., 2022; Bergelson & Swingley, 2013; Della Rosa et al., 2010; Lux et al., 2021; Pexman, 2019; Vigliocco et al., 2018) by demonstrating that it is not whether referents are concrete per se, but whether children themselves can perceive them directly. Second, we found that delays in language exposure (whether spoken or signed) were linked with delayed word production across modalities. We discuss the implications of each of our analyses in reference to these key results in turn.

In our first comparison, when controlling for age and lexical properties, we found that young blind children and their vocabulary-size-matched sighted peers were equally likely to produce words that were equally perceptible (i.e., auditory words) and equally imperceptible (i.e., abstract words). Blind children were, however, significantly and dramatically less likely to produce the highly visual words we tested. Convergently, other work finds that blind but not sighted children are more likely to produce visual words that can be experienced through other perceptual modalities, relative to words exclusively experienced through vision (Campbell et al., submitted). Notably, even early in childhood, when these highly visual words enter the lexicon, blind children have rich and nuanced semantic representations of their meanings. As Landau and Gleitman (1985) famously reported, "By age 36 months, [a blind child] was using these terms freely and frequently in conversation, in ways that seemed appropriate–except we knew she was blind" (pg. 52). In their landmark study, Landau and Gleitman (1985) showed that their subject, Kelli, had detailed semantic knowledge of colors words (e.g., ideas don’t have colors) and verbs of perception, and later work replicated this semantic sophistication finding in older children and adults (Bedny et al., 2019; Minervino et al., 2018; Striem-Amit et al., 2018). Our work does not refute this literature; rather, we show that the composition of the early lexicon differs in modality-specific ways, a point to which we later return.

In our second comparison, deaf children learning spoken language were significantly less likely to produce the 30 words we queried (across all modalities), compared to hearing peers who had the same overall vocabulary size. Finding a vocabulary delay for deaf spoken language children is consistent with prior work (Campbell & Bergelson, 2022a; González Cuenca et al., 2020; Takahashi et al., 2017; Yoshinaga-Itano et al., 2017), and may indicate a more general effect of delayed linguistic access on deaf children’s spoken vocabulary. One potential explanation for this result is that while the deaf and hearing children in this comparison were matched on overall productive vocabulary size and had similar length of language exposure (i.e. post-cochlear implant for the deaf group), the deaf group is ~13 months older (see Table 16). Thus, controlling for age statistically as we do may isolate the effects of access to auditory and linguistic information, resulting in the apparent vocabulary delay we find. Strikingly, the spoken vocabulary delays among deaf children were exacerbated for both types of imperceptible words: abstract and auditory. This may be because imperceptible meanings (such as those for abstract words) in particular are heavily scaffolded by language, so language delays affect imperceptible words disproportionately (as suggested by 50). Reassuringly, our results are convergent with (Jung et al., 2020), who find that older children with cochlear implants use more concrete nouns and fewer onomatopoeia and social words than their younger typically- hearing peers. However, it remains challenging to parcel out the effects of timing vs. quality and auditory vs. linguistic input, as the deaf spoken language and typically-hearing groups in our study differ from each other in timing and quality of auditory and linguistic input.

We approach this issue more directly in our third com- parison by measuring vocabulary acquisition in children with similar auditory input but differences in the timing and quality of language input. Again, controlling for age and lexical properties, we compared deaf children learning ASL from birth from deaf parents and deaf children receiving ASL from hearing parents after 6–42 months. If early access to language input differentially supports abstract words, we would expect to find that like the spoken language comparison above, abstract words would be disproportionately absent in the vocabularies of children with late access to sign. Instead, we found that both ASL groups were more likely to produce visual words relative to abstract words and less likely to produce auditory words than abstract words.

Lastly, to further probe the influence of language access on the production of abstract words, we combined two of our early language groups (typically-hearing and deaf early ASL) and our two late language groups (deaf spoken language and deaf late ASL). In this combined model, we show that delays in language access (independent of modality) result in delays in language production. Consistent with prior research

(Bellagamba et al., 2022; Bergelson & Swingley, 2013), we also found that abstract words were less likely to be produced than more concrete (in this case, visual) ones. How- ever, we did not find evidence that language access predicted production differentially for visual and abstract words.

Overall, our findings support the idea that domain-specific perceptual experience with a word's referent influences likelihood of production. The deaf early ASL, late ASL, and spoken language groups were less likely to produce auditory words than visual words; this was not the case for any of our three typically-hearing groups. The blind group was significantly less likely to produce visual words than other word types; this was not the case for any of our five typically-sighted groups.

That said, we caution against the interpretation that this pattern reflects a deficit for deaf or blind children. Rather, deaf and blind children may adaptively deprioritize words that refer to the imperceptible modality in favor of words that are more useful to their everyday experiences. These results do not suggest that children born deaf or blind are incapable of producing words about sound or sight; these children produced substantial numbers of words that were uniquely imperceptible to them (as well as abstract words). In our sample, blind children as young as 16 months were producing color words, and deaf children as young as 18 months were producing signs like HEAR. Given that such referents are perceptually unavailable or less available, the results support accounts positing that perceptual experience facilitates word learning, especially in early childhood (Muraki et al., 2022; Thill & Twomey, 2016), and underscore the strong role that language itself plays in relaying meaning regardless of sensory access (Landau & Gleitman, 1985).

In terms of language access, our results suggest that accessible language input is important for word learning, but does not differentially support abstract words vs. perceptible words, though this may be influenced by language modality. Deaf children learning spoken language through cochlear implants (i.e., no language access prior to implantation at 8–35 months) had lower production of our 30 words overall relative to hearing peers, but were especially less likely to produce abstract (vs. visual) words. However, we did not observe parallel differences in abstract word production between children with ASL exposure from birth relative to deaf children with delayed access to ASL (i.e., no language access for 6–42 months). Instead, we saw lower rates of abstract and auditory production but no difference between Early vs. Late ASL access. Combining these four groups in our exploratory analysis, we found overall access effects (later language access led to lower production of the targeted words) and overall modality effects (visual words were more likely to be produced than abstract ones), but these factors did not interact. That is, even with increased statistical power, the timing of language access did not disproportionately affect abstract words.

4.4.2 Limitations, Avenues for Future Research, and Conclusions

Our approach implicitly assumes that language exposure and perceptual experience are independent influences, but it is certainly plausible that these are inseparable. Although parents don’t seem to talk less to children with sensory impairments (Campbell et al., 2021; Dirks et al., 2020; VanDam et al., 2012), there is evidence that more fine-grained aspects of language input to children with sensory impairments may differ from language input to their typically-sighted/hearing peers (Ambrose et al., 2015; Andersen et al., 1993; Dirks et al., 2020; Pérez-Pereira & Conti-Ramsden, 2001). Furthermore, prior research suggests that parents of typically-sighted/hearing children tailor language input to things their children are presently attending (Tamis-LeMonda et al., 2013). If deaf children attend less to auditory stimuli and blind children attend less to visual stimuli, then it stands to reason that parents may talk less about these properties. Testing this idea awaits measures of naturalistic interactions between children with differential sensory access and their caregivers. Furthermore, while we looked at the role of age at first language exposure on abstract word production, cumulative language exposure may be a more sensitive measure. Capturing a more holistic picture of children's language exposure (e.g., audibility of spoken language, effectiveness and frequency of hearing aid/cochlear implant use, frequency of ASL exposure, fluency of parent in ASL (Hall, 2020; Hall & De, 2022) could help determine how and when the language signal is informative for acquiring the meaning of words, especially abstract ones. In the deaf population in particular, adopting a more nuanced measurement of language input could help reconcile differences between children learning spoken language and children learning sign language.

Lastly, these analyses target abstractness as imperceptibility. While a thorough consideration of imperceptibility, abstractness, and iconicity, and how these vary across language modalities and word-types is beyond the scope of this work, we look forward to further research aimed at pulling these factors apart.

Across three sets of analyses targeting the early vocabularies of children who vary in their access to visual, auditory, and linguistic information, young children were less likely to produce words that refer to an inaccessible perceptual modality: blind children were less likely to produce highly visual words and deaf children were less likely to produce highly auditory words. The potential role of language access in scaffolding acquisition of imperceptible meanings was less straightforward, but our exploratory analysis suggests that late access to language affects both perceptible and abstract words. Taken together, our findings build on a longstanding literature highlighting clear links between children's experiences and their emerging vocabularies. We add that these links are notably and differentially shaped by access to information about the world obtained both through language and the perceptual system, across wide-ranging and divergent early sensory and linguistic experiences.

4.5 Methods

We assessed children's vocabulary using the MacArthur-Bates Communicative Development Inventory (CDI), a widely used tool for assessing the vocabulary of young children (Frank et al., 2021). The CDI is a parent-report questionnaire assessing children's com- prehension and/or production of a specific set of words. The CDI is a reliable and valid measure of vocabulary in typically- developing children (Bates et al., 1994; Fenson et al., 1994), has been used with blind children (Campbell et al., submitted), and its validity has been evaluated for deaf children in both English (Thal et al., 2007) and ASL (Caselli et al., 2020). We use the CDI to compare the productive vocabulary composition for each of the groups of children analyzed below.

4.5.1 Participants and Matching

Across all six groups of participants, inclusion criteria were: (1) no suspected or diagnosed cognitive or developmental delay, (2) no additional vision or hearing impairment (beyond blindness in the blind group and deafness in the deaf groups), and (3) at least 75% of home language input is in the target language (English or ASL). Each participant in our test groups (blind, deaf spoken language, deaf late ASL) was matched on vocabulary size to *two* participants from our control groups (respectively: sighted, typically-hearing, and deaf early ASL). This doubling in sampling allows us to compare the word production of the difficult-to-recruit test groups to a more precise estimate of word production in the control groups; data for the control groups are pulled from Wordbank, a large database of CDI administrations (Frank et al., 2017). Participant ages and vocabulary sizes are summarized in Figure 15, and demographic information can be found in Table 16.

4.5.1.1 Blind and Sighted Samples

The blind sample consists of N = 36 congenitally blind children (13.90–57.10 months, M: 31.88 (11.67)), reported by a clinician or caregiver to have “no more than minimal light perception”; these data are described in depth in Campbell, Casillas, & Bergelson (submitted). Given that the CDI is normed for 16–30 months and that most blind children have an overall vocabulary relative to sighted peers (Campbell et al., submitted), the vocabulary-size-matched sighted sample is slightly but significantly younger than the blind sample by two-sample Wilcoxon Test (Mean difference = 4.80 months, W = 1,498.00, *p* < .001). These groups differ in visual access, but not in auditory access or timing of language access.

4.5.1.2 Deaf Spoken Language and Typically-Hearing

Second, we compare a sample of young cochlear implant users (N = 20, 20.00– 49.00 months, M: 34.74 (10.06)) to a Wordbank sample of typically-hearing children (N =40), again matching each deaf participant exactly on vocabulary size to two typically-hearing participants. For the deaf spoken language group, access to both the auditory signal and spoken language was delayed until children received cochlear implants (at 8.03–35.03 months, M: 14.72 (6.04)). Following cochlear implant activation, the auditory signal quality tends to be poorer for children with cochlear implants relative to typically-hearing children (Boothroyd & Eran, 1994; Nakisa et al., 2001). As a result, while the groups do not significantly differ in their *length of exposure* to language (Mean difference = 2.5 months, W =634.00, *p* = .110), the deaf spoken language group was significantly older than the vocabulary-size-matched typically-hearing group (Mean difference = 13.35 months, (W =1,264.00, *p* < .001). Therefore, these groups differ in timing and quantity of auditory and language access, but do not differ visual access.

Table 16: Age, vocabulary, and demographic characteristics of each of the groups in our analysis. For continuous variables, range, mean, and standard deviation are reported. Sex: F=Female, M=Male, U=Unknown. Race: A=Asian or Pacific Islander, B=Black or African American, NI=Native American or Indigenous, W=White, U=Unknown. Ethnicity: HL=Hispanic or Latino, NHL = Not Hispanic or Latino, U=Unknown. Assistive Listening Devices: HA=Hearing Aid, CI=Cochlear Implant, B=Both, N=None, U=Unknown.

Group	Age (months)	Language Experience (months)	Productive Vocabulary	Sex	Race	Ethnicity	Assistive Listening Device
Blind (N=36)	14–57 32.2 (11.6)	14–57 32.2 (11.6)	1–680 269 (254)	F: 50% M: 50%	B: 3% M: 6% NI: 3% O: 3% W: 56% U: 31%	HL: 14% NHL: 56% U: 31%	N: 100%
Sighted (N=72)	16–30 23.6 (4.4)	16–30 23.6 (4.4)	1–680 269 (252)	F: 32% M: 61% U: 7%	A: 1% B: 4% O: 7% W: 75% U: 12%	HL: 4% NHL: 39% U: 57%	N: 100%
Deaf Spoken Language (N=20)	21–49 34.9 (9.9)	9-39 21.1 (9)	3–678 265 (251)	F: 50% M: 50%	M: 5% W: 25% U: 70%	NHL: 30% U: 70%	CI: 100%
Typically-Hearing (N=40)	17–30 24 (4.3)	17–30 24 (4.3)	3–678 265 (247)	F: 35% M: 55% U: 10%	A: 5% B: 10% O: 10% W: 55% U: 20%	HL: 8% NHL: 0% U: 92%	N: 100%
Deaf Early ASL (N=72)	9–56 25.7 (9)	9–56 25.7 (9)	0–91% 34 (23)%	F: 44% M: 50% U: 6%	B: 18% M: 1% W: 72% U: 8%	HL: 8% NHL: 81% U: 11%	HA: 12% CI: 1% N: 86%
Deaf Late ASL (N=36)	12–59 38.5 (13)	4–43 22.1 (12)	1–90% 34 (23)%	F: 56% M: 44%	A: 17% B: 6% W: 75% U: 3%	HL: 14% NHL: 83% U: 3%	HA: 36% CI: 17% B: 33% N: 11% U: 3%

4.5.1.3 Deaf Early ASL and Deaf Late ASL

In our final analysis, we com- pare two groups of deaf children who use ASL: one learning ASL from birth from at least one deaf parent (deaf early ASL, originally described in Caselli, Lieberman, & Pyers, 2020) and one group of children learning ASL from non-fluent hearing parents after a period of 6–42 months (deaf late ASL, originally described in 63). For the late ASL group, only children whose parents reported using ASL "always" (N = 10), "often" (N = 14), or "sometimes" (N = 12) were included. After filtering the late ASL dataset to this subsample, we selected a subset of the early ASL group from Caselli et al. (2020) in order to match each late ASL group as closely as possible in age and productive vocabulary[5] to two early ASL participants. This resulted in a dataset of N = 72 Early ASL participants (9.00–56.00 months, M: 25.74 (9.01)) and N = 36 late ASL participants (12.00–59.00 months, M: 38.50 (13.05)); again, these groups differ significantly in age by 2-sample Wilcoxon test (Mean difference = 18.5 months, W = 1,115.00, $p < .001$) but not in length of language exposure (Mean difference = 2.5 months, W = 3,044.00, $p = .071$). Some of the children were reported to use assistive technology, and descriptively, this was more common in the late ASL group[6]. Caregivers of both groups of children completed the ASL CDI 2 (Caselli et al., 2020); this measure has been validated for use with hearing caregivers who may not be fully fluent in ASL. These

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[5] Unlike the blind/sighted and Deaf-Spoken Language/hearing groups above, for the ASL groups productive vocabulary matching was based on the *proportion* of produced words out of the number of words that parents responded to, given that on the ASL CDI, parents have the option to "skip" words (Caselli et al., 2021). While some administrations of the American English CDI also permit skipping, it is much more common for the Late ASL group in particular, given that caregivers are themselves learning ASL and are often not fluent. Previous analysis suggests that the proportion of produced words on a subset of the CDI is tightly correlated (R = 0.98) with the proportion of produced words on the entire CDI (Caselli et al., 2020).

[6] It's therefore possible that these groups also differ in auditory input, though given the wide variability among the deaf population in hearing level and hearing technology outcomes/use (Busch et al., 2018; E. E. Campbell & Bergelson, 2022a; Pasta et al., 2021), we cannot speculate without further audiological information (e.g., audiograms, hearing aid/cochlear implant use logs).

groups differ primarily in timing and quantity of language input, but not auditory or visual input.

4.5.2 Word Selection and Lexical Properties

4.5.2.1 English

For the blind, sighted, deaf spoken language, and typically-hearing groups we analyzed rates of reported production on the CDI for a set of English content words split into 3 sensory modalities: visual (N = 10), auditory (N = 10), and abstract (N = 10); see Table 17. The visual and auditory words were hand-selected as those deemed least perceptible through other modalities. This was confirmed through evaluating the chosen words via the Lancaster Sensorimotor Norms (Lynott et al., 2020), which showed that the selected visual and auditory words are highly concrete and have high visual and auditory ratings, respectively, and low ratings in other perceptual domains (see Figure 16). For abstract words, we selected words low in both concreteness (Brysbaert et al., 2014) and perceptual strength (Lynott et al., 2020) (excluding function words).

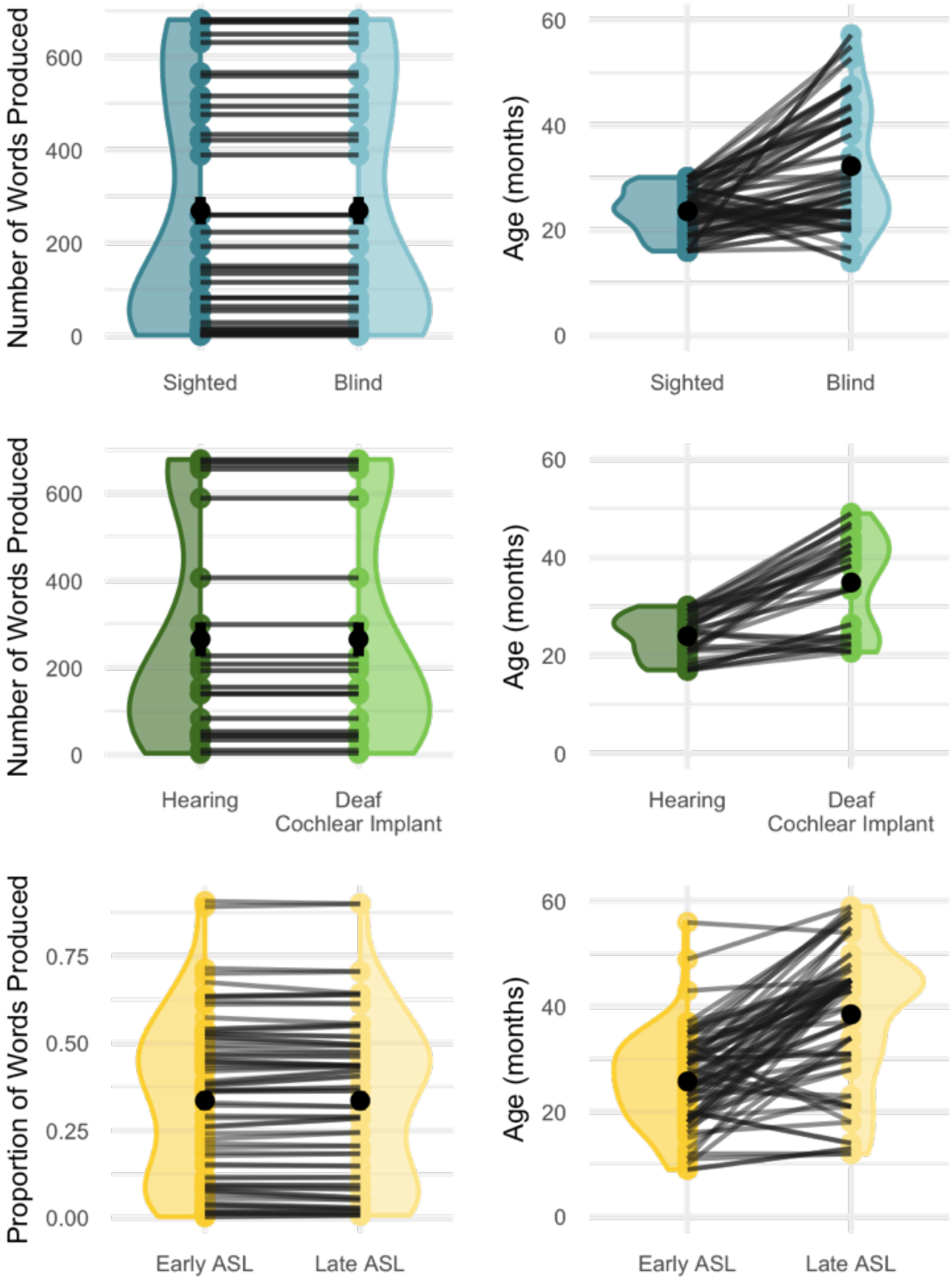

Figure 15: Age and productive vocabulary distributions for each of the samples. Each dot represents the age or vocabulary of one child in the sample. Black point with linerange depicts mean and standard error. Lines connect each participant in the blind, cochlear implant and late ASL groups to each of their two vocabulary-size matches; see text for details.

Table 17: Mean lexical properties by modality (with standard deviations in parentheses) for the English words (top) and ASL words (bottom) included in our analyses; see text for details and sources of lexical properties.

Modality	**English Words**	**Frequency**	**Syllables**	**Iconicity**
Abstract	good, bad, time, gentle, finish, wait, love, think, pretend, tomorrow	12,114.10 (14,864.39)	1.50 (0.71)	0.53 (1.13)
Auditory	cockadoodledoo*, grrr*, meow, moo, vroom*, hear, listen, loud, noisy, quiet	1,583.90 (1,880.21)	1.80 (1.23)	2.11 (1.43)
Visual	look, see, black, blue, brown, green, red, white, yellow, dark	15,705.00 (23,170.34)	1.10 (0.32)	0.99 (0.61)
Modality	**ASL Words (English Glosses)**	**Frequency**	**Phonological Complexity**	**Iconicity**
Abstract	good, bad, time, understand, finish, wait, love, think, pretend, tomorrow	6.31 (0.36)	1.57 (0.79)	3.29 (2.04)
Auditory	deaf, hear, hearing, hearing aid, radio, talk	4.23 (2.84)	1.50 (0.71)	2.05 (0.07)
Visual	black, blue, brown, green, mirror, pink, red, see, white, yellow	5.07 (0.56)	1.33 (0.71)	1.59 (0.98)

In order to control for relevant word-level properties statistically, we also computed frequency, phonological complexity, and iconicity. Frequency was calculated using the childesdb package (Sanchez et al., 2019) based on how often children heard our 30 words in the North American English corpora in CHILDES, a database of child-centered language (MacWhinney, 2014). Word frequency was then converted to a log scale given its Zipfian distribution (Lavi-Rotbain & Arnon, 2022). As a proxy for phonological complexity (i.e. how challenging the word is to produce), we also include number of syllables in the citation form of the word. Iconicity ratings come from Winter 2017, wherein participants rated words on a scale from -5 (word sounds like the opposite of its meaning; not iconic at all) to 5 (word sounds like what it means; highly iconic).

4.5.2.2 ASL

For the early and late ASL groups, we selected visual (N = 10), auditory (N = 6), and abstract (N = 10) words from the ASL CDI 2.0 in the same manner as word selection for the English CDI. As might be expected, the ASL CDI contains fewer exclusively "auditory" words than the American English CDI. When possible, we selected English/ASL words translation equivalents of each other; this was the case for 9/10 abstract words and 8/10 visual words but only 1/10 of the auditory words (only hear/hear). We used lexical ratings from ASL-LEX (Caselli et al., 2017; Sehyr et al., 2021); see Table 17 and Figure 16. To summarize these lexical properties briefly, frequency ratings were produced by a sample of Deaf signers rated how often they felt the sign appears in everyday conversation on a scale from 1 (*very infrequently*) to 7 (*very frequently*)(Caselli et al., 2017). Phonological complexity refers to the number of complex features (Morgan et al., 2019) the sign has; this score can range from 0 (no complex features) to 7 (contains all seven features). Like the syllables measure for spoken language, signs that are more phonologically complex tend to be longer in duration, less frequent, and acquired later (Caselli & Pyers, 2017, 2020; Sehyr et al., 2021). For iconicity, we used ratings from deaf native signers when available; deaf signers were asked to rate signs on a scale from 1 (*not iconic at all*) to 7 (*highly iconic*) For five of the words (white, deaf, pink, tomorrow, hearing), Deaf native signer ratings were unavailable, and ratings from hearing non-signers for the signs (using the same rating procedure) were substituted (Caselli et al., 2017).

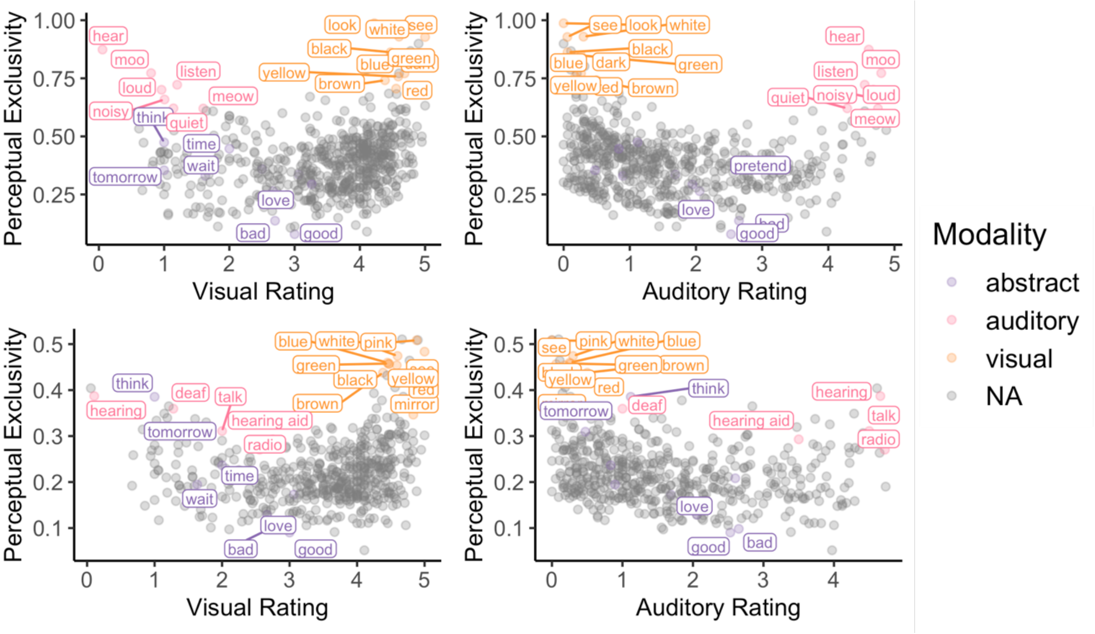

Figure 16: CDI words plotted by A. Visual Rating and Perceptual Exclusivity, B. Auditory Rating and Perceptual Exclusivity. Selected words are labelled and colored by perceptual modality (visual, auditory, or abstract). Top row: American English Words and Sentences form. The auditory words cockadoodledoo, vroom, and grrr are omitted because they are not rated in the Lancaster Sensorimotor Norms. Bottom row: ASL CDI 2.0, plotted by perceptual rating for their English gloss. The auditory word HEARING is omitted from this figure because it is not rated.

5. Comparing Language Input in Homes of Blind and Sighted Children: Insights from Daylong Recordings

5.1 Introduction

The early language skills of blind children are highly variable (Campbell et al., submitted), with some blind children demonstrating age-appropriate vocabulary from the earliest stages of language learning (Bigelow, 1987; Campbell et al., submitted; Landau & Gleitman, 1985), while others experience substantial language delays (Campbell et al., submitted). By adulthood, blind individuals are fluent speakers and even have faster lexical processing skills than sighted adults (Loiotile et al., 2020; Röder et al., 2000, 2003). The causes of early variability and the later ability to "catch up" remain poorly understood: what could make the language learning problem different and initially more difficult for the blind child? Here, we compare the language environments of blind children to that of their sighted peers. In doing so, we begin to untangle the role that perceptual input plays in shaping children's language environment, and better understand the interlocking factors that may contribute to variability in blind children's early language abilities.

5.1.1 Why would input matter?

Among both typically-developing children and children with developmental differences, language input can predict variability in language outcomes (Anderson et al., 2021; Gilkerson et al., 2018; Huttenlocher et al., 1991, 2010; Rowe, 2008, 2012). There are many ways to operationalize language input, that tend to be grouped into **quantity**

of language input and **input characteristics** (often discussed as **quality of language input**[7], c.f. MacLeod & Demers, 2023). Quantity can be broadly construed as the number of words or utterances a child is exposed to. At a coarse level, children who are exposed to more speech (or sign, Watkins et al., 1998) tend to have better language outcomes (Anderson et al., 2021; Gilkerson et al., 2018; Huttenlocher et al., 1991; Rowe, 2008). However, if only the *amount* of language exposure mattered, then infants should be able to sit in front of the television all day and become fluent language users. Yet young children struggle to learn language just from exposure to large quantities of speech (e.g., Roseberry et al., 2014), so something about the *type* of language input must matter. The specific characteristics of language input are perhaps even more influential (Hirsh-Pasek et al., 2015; Rowe, 2012), although it is somewhat trickier to split into discrete measures. Rowe and Snow (Rowe & Snow, 2020) divide this space into three dimensions: interactive features (e.g., parent responsiveness, speech directed *to* child vs. overheard, conversational turn-taking), linguistic features (e.g., lexical diversity, grammatical complexity), and conceptual features (i.e., the extent to which input focuses on the *here-and-now*).

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[7] In the present study, we move away from describing these linguistic characteristics as "quality" measures. In the field thus far, the directionality of the term "quality" has favored the types of language used by white and abled groups as immutable universal standards, thereby framing racialized and disabled peoples' language as deficit and "low quality" by nature. Describing a singular source of input variation as "high quality" ignores the sociocultural variation of talk styles, and the presence of many rich sources of information from which children can learn (MacLeod & Demers, 2023).

Prior literature reports that back-and-forth communicative exchanges (also known as conversational turns) between caregivers and children predict better language outcomes across infancy (Donnellan et al., 2020; Goldstein & Schwade, 2008) and toddlerhood (Hirsh-Pasek et al., 2015; Romeo et al., 2018). Another way to quantify the extent to which caregivers and infants interact during language input is by looking at how much speech is directed *to* the child (as opposed to, for example, an overheard conversation between adults). The amount of child-directed speech in children's input (at least in Western contexts, Casillas et al., 2020) is associated with children's vocabulary and lexical processing (Rowe, 2008; Shneidman et al., 2013; Weisleder & Fernald, 2013).

We broadly define the linguistic characteristics of input as *which* words are used and how they are *combined*, both of which have measurable associations with children's language growth. Two commonly-analyzed linguistic features are lexical diversity (often measured as type/token ratio) and syntactic complexity (often measured by mean length of utterance). Sighted toddlers who are exposed to greater diversity of words in their language input are reported to have larger vocabulary scores (Anderson et al., 2021; Hsu et al., 2017; Huttenlocher et al., 2010; Rowe, 2012; Weizman & Snow, 2001). Likewise, the diversity and complexity of syntactic constructions in parental language input is associated with both children's vocabulary growth and structural diversity in their own productions (De Villiers, 1985; Hadley et al., 2017; Hoff, 2003; Huttenlocher et al., 2002, 2010; Naigles & Hoff-Ginsberg, 1998).

The conceptual dimension of language input aims to capture the extent to which the language signal maps onto present objects and ongoing events in children's environments (Rowe & Snow, 2020). As children develop, their ability to represent abstract, decontextualized referents improves (Bergelson & Swingley, 2013; Kramer et al., 1975; Luchkina et al., 2020). Decontextualized language input– that is, talking about past, future, or hypothetical events, or people and items that are not currently present in the environment– may be one contributing factor (Rowe, 2013); greater decontextualized language use in speech to toddlers predicts aspects of children's own language in kindergarten and beyond (Demir et al., 2015; Rowe, 2012, 2013; Uccelli et al., 2019).

From this review, it appears that sighted children learn about the world and language simultaneously from sensory perception, linguistic input, and conceptual and social knowledge. Many of these cues are visual: sighted children can utilize visual information like parental gaze, shared visual attention (Tomasello & Farrar, 1986), pointing (Lucca & Wilbourn, 2018), and the presence of salient objects in the visual field (Yu & Smith, 2012). There are also non-visual cues to word meaning. Syntactic structure in particular provides cues to word meaning that may be lost without visual cues, such as the relationship between two entities that aren't within reach (Gleitman, 1990). For blind children however, because visual cues are inaccessible, language input may take on a larger role in the discovery of word meaning (Campbell & Bergelson, 2022b). However, we cannot assume that access to visual experience is the *only* difference in the language learning experiences for blind and sighted children; the language input itself may differ between blind children and sighted children.

5.1.2 Why would the input differ?

Speakers regularly tailor input to communicate efficiently with the listener (Grice, 1975). Parents are sensitive to their child's developmental level and tune language input accordingly (Snow, 1972; Vygotsky, 1978). Child-directed speech is one example–wherein parents speak to young children with exaggerated prosody, slower speech, and increased vowel clarity (Bernstein Ratner, 1984; Fernald, 1989), which is in some cases helpful to the young language learner (Thiessen et al., 2005). For instance, parents repeat words more often when interacting with infants than with older children or adults (Snow, 1972). Communicative tailoring is also common in language input to children with disabilities, who tend to receive simplified, more directive language input, and less interactive input compared to typically-developing children (Dirks et al., 2020; Yoshinaga-Itano et al., 2020).

In addition to tailoring communication to children's developmental level, speakers also adjust their conversation in accordance with the conversation partner's sensory access (Gergle et al., 2004; Grigoroglou et al., 2016). In a noisy environment, speakers will adapt the acoustic-phonetic features of their speech to make it easier for their interlocutor to understand them (Hazan & Baker, 2011), which demonstrates sensitivity to even temporary sensory conditions of their conversation partner. When describing scenes, speakers aim to provide the information their listeners lack but avoid redundant visual description (Grice, 1975; Ostarek et al., 2019). During in-lab tasks with sighted participants, participants verbally provide visually-absent cues when an object is occluded to their partner (Hawkins et al., 2021; Jara-Ettinger & Rubio-Fernandez, 2021; Rubio-Fernandez, 2019). These results suggest that adults and even infants (Chiesa et al., 2015; Ganea et al., 2018; Senju et al., 2013) can flexibly adapt communication to the visual and auditory abilities of their partner.

Taking these results into account, we might expect parents to verbally compensate for missing visual input, perhaps providing more description of the child's environment. Prior research doesn't yield a clear answer. Several studies suggest differences in the concepts parents discuss: caregivers of blind children restrict conversation to things that the blind child is currently engaged with, rather than attempt to redirect their attention to other stimuli (Andersen et al., 1993; Campbell, 2003; Kekelis & Andersen, 1984; though c.f., Moore & McConachie, 1994). Studies of naturalistic input to blind children report that parents use *fewer* declaratives and *more* imperatives than parents of sighted children, suggesting that blind children might be receiving less description than sighted children (Kekelis & Andersen, 1984; Landau & Gleitman, 1985). Other studies report that parents adapt their interactions to their children's visual abilities, albeit in specific contexts. Tadić, Pring, and Dale (2013) find that in a structured book reading task, parents of blind children provide more descriptive utterances than parents of sighted children. Further, parents of blind children provide more tactile cues to initiate interactions or establish joint attention (Preisler, 1991; Urwin, 1983, 1984), which may serve the same social role as shared gaze in sighted children. These mixed results suggest that parents of blind children might alter language input in some domains but not others. The apparent conflict in results may be exacerbated by the difficulty of recruiting specialized populations to participate in research: the small (in most cases, single-digit) sample sizes of prior work limits our ability to generalize about any principled differences in the input to blind infants.

5.1.3 The Present Study

Reaching a better understanding of how sensory perception and linguistic input interact to influence blind children's language outcomes is of scientific, clinical, and educational importance. If properties of language input influence the likelihood of language delays among blind infants and toddlers (Campbell et al., submitted), capturing this variation may reveal a more nuanced picture of how infants use the input to learn language. In the present study, we examine daylong recordings of the naturalistic language environments of blind and sighted children in order to characterize the input to each group. Using both automated measures and manual transcription of these recordings, we measure input quantity (adult word count) and analyze several characteristics that have been previously suggested to be information-rich learning cues, including interaction (conversational turn counts, proportion of child-directed speech), conceptual features (temporal displacement, sensory modality), and linguistic complexity (type/token ratio and mean length of utterance).

5.2 Methods

5.2.1 Participants

15 blind infants and their families participated in this study. Blind participants were recruited through ophthalmologist referral, preschools, early intervention programs, social media, and word of mouth. To be eligible for this study, participants had to be 6–30 months old, have no additional disabilities (developmental delays; intellectual disabilities, or hearing loss), and be exposed to ≥ 75% English at home. To control for the wide age range of the study, each blind participant was matched to a sighted participant, based on age (± 6 weeks), gender, maternal education (± one education level), and number of siblings (± 1 sibling). We prioritized matching each characteristic as closely as possible in the preceding order. Caregivers were asked to complete a demographics survey and the MacArthur-Bates Communicative Development Inventory (CDI, Fenson et al., 1994) within one week of the home language recording. See Table 18 for sample characteristics.

Table 18: Demographic characteristics of the blind and sighted samples. Range and Mean (SD) are provided for continuous variables.

Group	Age (months)	Sex	Race	Number of Older Siblings	Maternal Education Level	Vision Diagnosis
Blind (N=15)	6–30, 15.8 (8.2)	Female: 44%, Male: 56%	American Indian or Alaska Native: 6%, Black or African American: 6%, Mixed: 19%, White: 69%	0–2, 0.5 (0.8)	Some college: 19%, Associate's degree: 6%, Bachelor's degree: 31%, Master's degree: 25%, Doctoral degree: 19%	Cataracts: 19%, Leber's Congenital Amaurosis : 6%, Microphthalmia : 12%, Multiple: 12%, Not specified: 12%, Ocular albinism: 12%, Optic Nerve

						Hypoplasia: 12%, Retinal Detachments: 6%, Retinopathy of Prematurity: 6%
Sighted (N=15)	6–32, 16.1 (8.1)	Female: 44%, Male: 56%	Black or African American: 6%, Mixed: 6%, Unknown: 44%, White: 44%	0–3, 1.1 (1)	Some college: 6%, Associate's degree: 12%, Bachelor's degree: 56%, Master's degree: 6%, Doctoral degree: 0%	*NA*

5.2.2 Recording Procedure

For the recording portion of the study, caregivers of participating infants received a LENA wearable audio recorder and vest (Ganek & Eriks-Brophy, 2018; Gilkerson & Richards, 2008). They were instructed to place the recorder in the vest on the day of their scheduled recording and put the vest on their child from the time they woke up until the recorder automatically shut off after 16 hours (setting the vest nearby during baths, naps, and car rides). They were also informed how to pause the recording at any time, but asked to keep pauses to a minimum. Actual recording length ranged from 8 hours 17 minutes to 15 hours 59 minutes (Mean: 15 hours 16 minutes).

5.2.3 Processing

The audio recordings were first processed by LENA proprietary software (Xu et al., 2009), creating algorithmic measures such as conversational turn counts and adult word count. Each recording was then run through an in-house automated sampler that selected 15- non-overlapping 5-minute segments, randomly distributed across the duration of the recording. Each segment consists of 2 core minutes of annotated time, with 2 minutes of listenable context preceding the annotation clip and 1 minute of additional context following. Because these segments were sampled randomly, across participants roughly 27% of the random 2-minute coding segments contained no speech at all. For questions of *how much does a phenomenon occur*, random sampling schemes can help avoid overestimating speech in the input, but for questions of input *content*, randomly selected samples may be too sparse (Pisani et al., 2021).

Therefore, we chose to annotate 5 additional segments specifically for their high density of speech. To select these segments of dense talk, we first conducted an automated analysis of the audio file using the voice type classifier for child-centered daylong recordings (Lavechin et al., 2021) which identified all human speech in the recording. The entire recording was divided into 2-minute chunks, each ranked highest to lowest by the total duration of speech contained within the chunk. We annotated the highest-ranked 5 segments of each recording. These high volubility segments allow us to more closely compare our findings to studies classifying the input during structured play sessions, which paint a denser and differently-proportioned makeup of the language input (Bergelson et al., 2019). In sum, 30 minutes of randomly sampled input and 10 minutes of high-volubility input (40 minutes total) were annotated per child.

5.2.4 Annotation

Recordings were annotated using the ELAN software (Brugman & Russel, 2009). Trained annotators listened through each 2-minute segment plus its surrounding context and coded it using the Analyzing Child Language Experiences around the World (ACLEW) Daylong Audio Recording of Children's Linguistic Environments (DARCLE) annotation scheme (Soderstrom et al., 2021). For more information about this scheme, see the ACLEW homepage. For each recording, annotators segmented the duration of each utterance on a separate coding tier for each unique speaker. Speech by people other than the target child was transcribed using an adapted version of the CHAT transcription style (MacWhinney, 2019; Soderstrom et al., 2021). Because the majority of target children in the project are pre-lexical, utterances produced by the target child are not yet transcribed. Environmental speech was then classified by the addressee of each utterance: child, adult, both an adult and a child, pets or other animals, unclear addressee, or a recipient that doesn't fit into another category (e.g., voice control of Siri or Alexa, prayer to a metaphysical entity). Following the first pass, all files were reviewed by a highly-trained "superchecker" to ensure the consistency of annotations.

5.2.5 Extracting Measures of Language Input

To go from our dimensions of interest (quantity, interaction, linguistic, conceptual), to quantifiable properties, we used a combination of automated measures (generated by the proprietary LENA algorithm, Xu et al., 2009) and manual measures (generated from the transcriptions made by our trained annotators). Quantity and interaction analyses were conducted on the random samples only, to capture a more representative estimate. Linguistic and conceptual analyses were conducted on all available annotations in order to maximize the amount of speech over which we could calculate them. These measures are summarized in Table 19.

5.2.5.1 Quantity.

5.2.5.1.1 Adult Word Count.

To derive this count, first the LENA algorithm segments the recording into clip which are then classified as female adult speech, male adult speech, target child, other child, overlapping vocalization/noise, electronic noise, noise, silence, or uncertain, each of which is further categorized into "near" or "far". Only segments that are classified as nearby male or female adult speech are included in the Adult Word Count estimation (Xu et al., 2009). Validation work suggests that this automated count correlates strongly with word counts derived from manual annotations (r = .71 – .92, Lehet et al., 2021), but Lehet et al. (2021) find that the amount of error may vary substantially across families. However, meta-analytic work finds that AWC is associated with children's language outcomes across developmental contexts (e.g., autism, hearing loss, Wang et al., 2020). Because the recordings varied in length (8 hours 17 minutes to 15 hours 59 minutes), we normalized AWC by dividing by recording length[8].

5.2.5.1.2 Manual Word Count.

We also calculated a manual count of speech in the children's environment. Manual word count is simply the number of intelligible words in our transcriptions of

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[8] To make this comparable to the manual word count estimates, which are derived from the 30 minutes of randomly sampled annotation, we calculate AWC per half hour.

each child's recording. Speech that was too far or muffled to be intelligible, as well as speech from the target child and electronic speech (TV, radio, toys) are excluded from this count.

By using Adult Word Count and Manual Word Count, we hope to capture complementary estimates of the amount of speech children are exposed to. AWC is less accurate, but commonly used, and provides an estimate of the speech across the whole day. MWC, because it comes from human annotations, is the gold-standard for accurate speech estimates, but is only derived from 30 minutes of the recording.

5.2.5.2. Interaction.

5.2.5.2.1 Conversational Turn Count.

One common metric of communicative interaction (e.g., Ganek & Eriks-Brophy, 2018; Magimairaj et al., 2022) is conversational turn count (or CTC), an automated measure generated by LENA (Xu et al., 2009). Like AWC, a recent meta-analysis finds that CTC is associated with children's language outcomes (Wang et al., 2020). After tagging vocalizations for speaker identity, LENA algorithm looks for alternations between adult and target child speech in close temporal proximity. The algorithm counts any temporally close (within 5 seconds) switch between adult and target child vocalizations, which can erroneously include non-contingent interactions (e.g., mom talking to dad while the infant babbles to herself nearby), and therefore inflate the count especially for younger ages and in houses with multiple children (Ferjan Ramírez et al., 2021). Still, this measure correlates moderately well with manually-coded conversational turns (Busch et al., 2018; Ganek & Eriks-Brophy, 2018), and because participants in our sample are matched on both age and number of siblings, CTC overestimation should not be systematically biased towards either group.

5.2.5.2.2 Proportion of Child-Directed Speech.

Our other measure of interaction is the proportion of utterances that are child-directed, derived from the manual annotations. Each proportion was calculated as the number of utterances (produced by someone *other* than the target child) tagged with a child addressee out of the total number of utterances.

5.2.5.3 Linguistic Features.

5.2.5.3.1 Type-Token Ratio.

As in previous work (e.g., Montag et al., 2018; Pancsofar & Vernon-Feagans, 2006; Templin, 1957), we calculated the lexical diversity of the input by dividing the number of unique words by the total number of words (i.e., the type-token ratio). Because the type-token ratio changes as a function of the size of the language sample (Montag et al., 2018; Richards, 1987), we first standardized the sample length by cutting children's input (from the manual annotations) in each recording into 100-word bins. We then calculated the type-token ratio within each of these bins by dividing the number of unique words in each bin by the number of total words (~100) and then averaged the type-token ratio across bins for each child.

5.2.5.3.2 MLU.

We also analyzed the syntactic complexity of children's language input, approximated as mean utterance length in morphemes. Both type-token ratio and mean length of utterance in speech to infants are consistent within individual caretakers, in and out of lab settings (Stevenson et al., 1986). Each utterance was tokenized into morphemes using the 'morphemepiece' R package (Bratt et al., 2022). We then calculated the mean length of utterance (number of morphemes) per speaker in each audio recording. We manually checked utterance length in a random subset of 10% of the utterances, which yielded an intra-class correlation coefficient of 0.94 agreement with the udpipe approach ($p < .001$), indicating high consistency.

5.2.5.4 Conceptual Features.

Our analysis of the conceptual features aims to measure whether the extent to which language input centers around the *"here and now"*: things that are currently present or occurring that a child may attend to in real time. Prior work has quantified such *here-and-now*ness by counting object presence co-occurring with a related noun label (e.g., Ganea & Saylor, 2013; Harris et al., 1986; Moore & McConachie, 1994; Osina et al., 2013). The audio format of our data makes it difficult to ascertain object presence, so instead of object displacement, we approximate *here-and-now*ness using lexical and morphosyntactic properties of the input. We ask 1) What proportion of utterances are temporally displaced?; 2) To what extent can children physically engage in or interact with words' referents?; and 3) What proportion of words have referents that can only be experienced through vision?

5.2.5.4.1. Proportion of temporally displaced verbs.

We examined the displacement of events discussed in children's linguistic environment, via properties of the verbs in their input. Notably, we are attempting to highlight semantic features of the language environment; however, given the constraints of large-scale textual analysis, we are categorizing utterances based on a combination of closely related syntactic and morphological features of verbs, since these contain some time information in their surface forms. We assigned each utterance a **temporality** value: utterances tagged *displaced* describe events that take place in the past, future, or irrealis space, while utterances tagged *present* describe current, ongoing events. This coding scheme roughly aligns with both the temporal displacement and future hypothetical categories in Grimminger et al., 2020; Hudson, 2002; see also: Lucariello & Nelson, 1987. To do this, we used the udpipe package (Wijffels, 2023) to tag the transcriptions with parts of speech and other lexical features, such as tense, number agreement, or case inflection. To be marked as present, a verb either had to be marked with both present tense and indicative mood, or appear in the gerund form with no marked tense (e.g. *you talking to Papa?*). Features that could mark an utterance as displaced included past tense, presence of a modal, presence of *if*, or presence of *gonna/going to*, *have to*, *wanna/want to*, or *gotta/got to*, since these typically indicate future events, belief states and desires, rather than real-time events. In the case of utterances with multiple verbs, we selected the features from the first verb or auxiliary, as a proxy for hierarchical dominance. A small number of utterances in our corpus were left *uncategorized* (n = 1512/9776), either because they were fragments or because the automated parser failed to tag any of the relevant features. We manually checked verb temporality in a random subset of 10% of the utterances (n = 936); human judgments of event temporality aligned with the automated tense tagger 76%, indicating reasonably high reliability of this measure.

5.2.5.4.2 CBOI distribution.

Next, we measured whether the distribution of Child-Body-Object Interaction (CBOI) rating differed across groups (Muraki et al., 2022). These norms were generated by asking parents of six-year-olds to rate the extent to which children physically interact with words' referents, from 1 (*things that a typical child does not easily physically interact with*) to 7 (*things a typical child would easily physically interact with*). These ratings are another measure of the amount of sensorimotor information wrapped up in language input to children, which may make certain words easier to learn and process (Muraki et al., 2022). We first use the udpipe part-of-speech tags to filter to content words (adjectives, adverbs, nouns, and verbs). Words without a CBOI rating (N = 5639/32704) were removed.

5.2.5.4.3 Proportion of highly visual words.

In addition to these two more general measures of decontextualized language, we include one measure that is uniquely decontextualized for blind children: the proportion of words in the input with referents that are highly and exclusively visual. We categorize the perceptual modalities of words' referents using the Lancaster Sensorimotor Norms, ratings from typically-sighted adults about the extent to which a word evokes a visual/tactile/auditory/etc. experience (Lynott et al., 2020). Words with higher ratings in a given modality are more strongly associated with perceptual experience in that modality. A word's dominant perceptual modality is the modality which received the highest mean rating. We tweak this categorization in two ways: words which received low ratings (< 3.5/5) across all modalities were re-categorized as *amodal*, and words whose ratings were distributed across modalities (perceptual exclusivity < 0.5/1) were re-categorized as *multimodal*. Using this system, each of the content words in children's input (adjectives, adverbs, nouns, and verbs) were categorized into their primary perceptual modality. For each child, we extracted the proportion of exclusively "visual" words in their language environment.

Table 19: Language input variables extracted from recordings.

Variable	**Coding**	**Portion of Recording**	**Description**
Adult Word Count / half hour (AWC)	Automated	Whole day	Estimated number of words in recording categorized as nearby adult speech by LENA algorithm
Manual Word Count (MWC)	Manual	Random	Number of word tokens from speakers other than target child
Conversational Turn Count / half hour (CTC)	Automated	Whole day	Count of temporally close switches between adult and target-child vocalizations, divided by recording length
Proportion of Child-Directed Speech (Prop. CDS)	Manual	Random	Number of utterances tagged with child addressee out of total number of utterances, from speakers other than target child
Type-Token Ratio	Manual	Random + High-Volume	Average of the type-token ratios (number of unique words

			divided by number of total words) for each of the 100-word bins in their sample
Mean Length of Utterance (MLU)	Manual + Automated Parsing	Random + High-Volume	Average number of morphemes per utterance
Proportion of Temporally Displaced Verbs (Prop. Displaced)	Manual + Automated Tagging	Random + High-Volume	Proportion of verbs that refer to past, future, or hypothetical events
Child-Body-Object Interaction Ratings (CBOI)	Manual + Automated Tagging	Random + High-Volume	Distribution of ratings of "how much a child can interact with" each word (adjectives, adverbs, nouns, verbs)
Proportion of Highly Visual Words (Prop. Visual)	Manual	Random + High-Volume	Proportion of words in the input with high visual association ratings and low ratings for other perceptual modalities

5.3 Results

Our study assesses whether language input to blind children is different from the language input to sighted children, along the dimensions of quantity, interaction, linguistic properties, and conceptual properties. We test for group differences using paired t-tests or the non-parametric Wilcoxon signed rank tests, when a Shapiro-Wilks test indicates that the variable is not normally distributed. Because this analysis involves multiple tests against the null hypothesis (*that there is no difference in the language input to blind vs. sighted kids*), we use the Benjamini-Hochberg correction (Benjamini & Hochberg, 1995) to control false discovery rate (Q = .05) for each set of analyses (quantity, interaction, linguistic, conceptual). The results of these analyses are summarized in Table 20.

5.3.2 Language Input Quantity.

We first compare the quantity of language input to blind and sighted children using two measures of the number of words in their environment: LENA's automated Adult Word Count and Manual Word Count. Shapiro-Wilks tests indicated that both of these variables were normally distributed (*p*s > .05). Because the quantity analysis consists of two statistical tests, our Benjamini-Hochberg critical values were $p < 0.025$ for the smallest *p* value and $p < 0.05$ for the larger *p* value.

Turning first to LENA's automated measure, a two-sample t-test shows that despite wide variability in the number of words children hear (Range: 195–992 $\text{words}_{\text{blind}}$, 238–804 $\text{words}_{\text{sighted}}$), blind and sighted children do not differ in language input quantity ($t(15) = 163$, $p = .243$). If we instead measure this using word counts from the transcriptions of the audio recordings, we find parallel results: blind and sighted children do not differ in language input quantity ($t(15) = 1.18$, $p = .255$); see Figure 17.

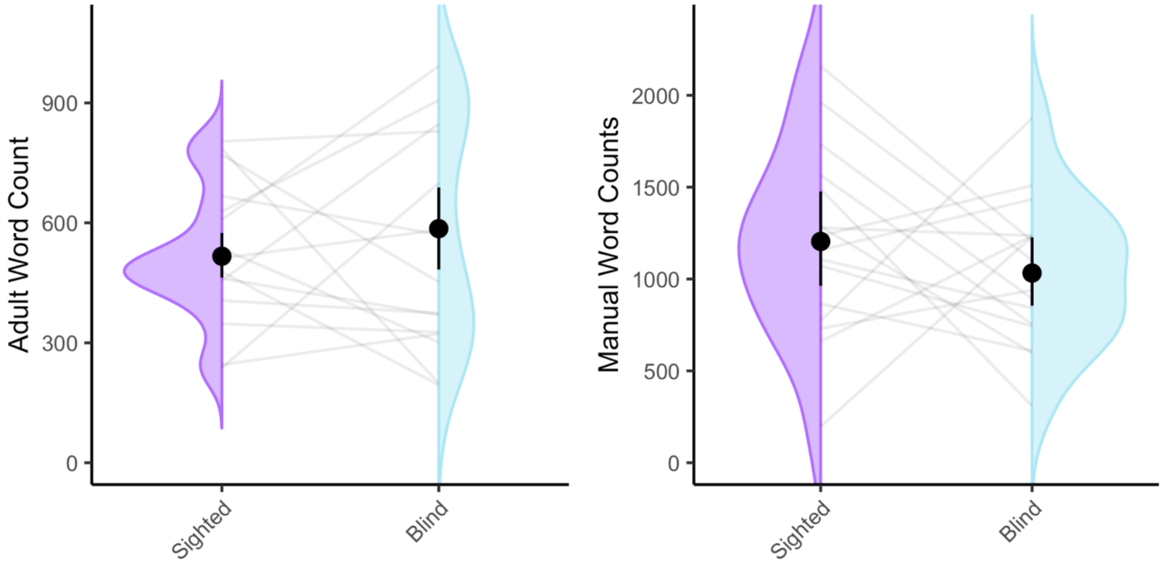

Figure 17: Comparing LENA-generated adult word counts (left) and transcription-based word counts in the input of blind and sighted children. Each dot represents the estimated number of words in one child's recording.

5.3.2 Interaction.

Next, we ask whether blind and sighted groups differ in the amount of interaction with the child, by comparing the proportion of child-directed speech and the number of conversational turns. Both measures were normally distributed (Prop. CDS: W = 0.97, *p* = .969; CTC: W = 0.88, *p* = .878). This set of analyses also involves two tests, so our Benjamini-Hochberg critical values were $p < 0.03$ and 0.05. Paired t-tests revealed no significant difference in the proportion of child-directed speech (*t(15)* = 0.06, *p* = .952) or in conversational turn counts to blind children versus to sighted children (see Figure 18).

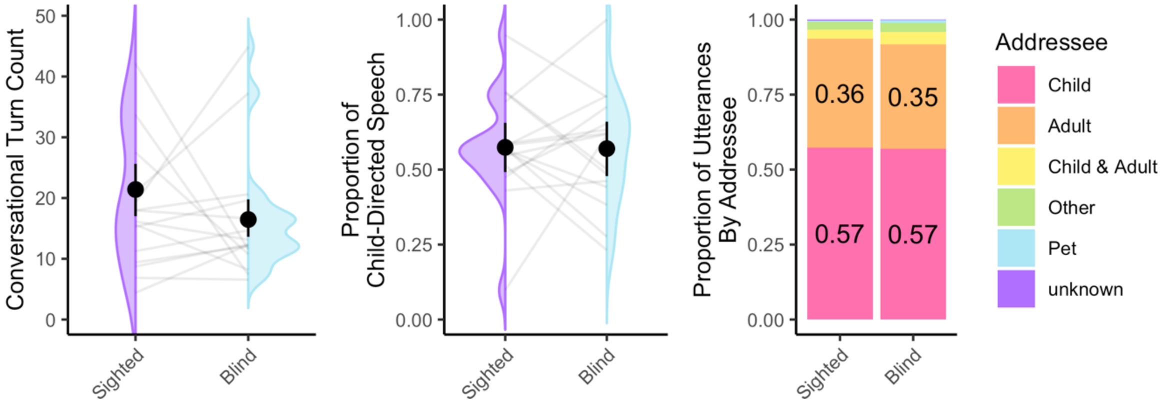

Figure 18: Comparing LENA-generated conversational turn counts (left) and proportion of utterances in child-directed speech (center). Each dot represents one child's recording. The full breakdown by addressee is shown in the rightmost panel.

5.3.3 Linguistic Features.

For linguistic features, we measure type-token ratio and mean length of utterance, two variables derived from the manual annotations. Because these variables met the normality assumption (TTR: W = 0.97, *p* = .965; MLU: (W = 0.94, *p* = .937)), we performed paired t-tests. Again, the critical values for significance were *p* < .025 and .050. Both variables differed across groups: blind children had a significantly higher type-token ratio (*t*(15) = -2.25, *p* = .040), and significantly longer MLU than to their sighted peers (*t*(15) = -2.51, *p* = .024); see Figure 19).

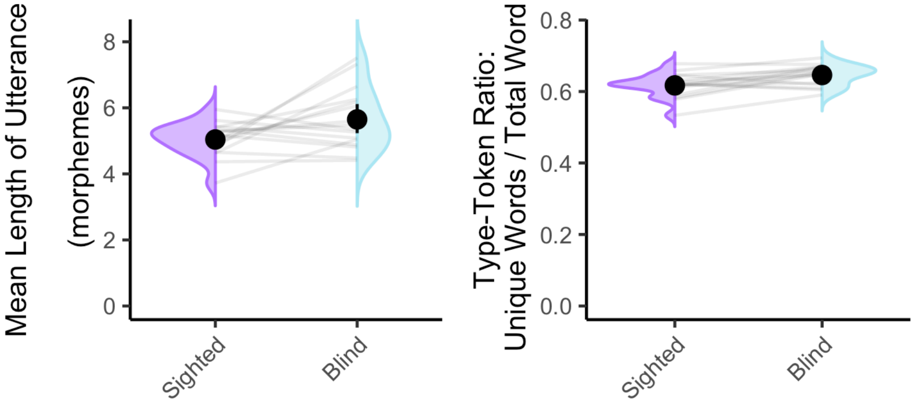

Figure 19: Comparing linguistic features: Mean length of utterance (left) and Type-token ratio (right). Each dot represents one child's recording.

5.3.4 Conceptual Features.

Lastly, we compared three measures of the conceptual features of language input: the proportion of temporally displaced verbs, the distribution of Child-Body-Object Interaction ratings across words in the input, and the proportion of highly visual words. This set of analyses involves three tests, so our Benjamini-Hochberg critical values for significance are $p < .017$, .033, and .050, for the smallest, middle, and largest p values, respectively. Because the proportion of displaced verbs follows a normal distribution (W = 0.96, $p = .960$), we tested this measure with a paired t-test and found that blind children hear proportionally more displaced verbs than sighted children ($t(15) = -2.77$, $p = .014$). Next, we compared the distribution of CBOI ratings in word tokens in blind children's input to that in sighted children's input using a two-sample Kilgomorov-Smirnov test (which tests for differences in distribution). These distributions significantly differ (D = 0.98, $p < .001$). Descriptively, low CBOI words were more common in language input to blind children, and high CBOI words were more common in language input to sighted children; see Figure 20. For the proportion of highly visual words, a Shapiro-Wilks test showed that this variable was not normally distributed (W = 0.88, *p* = .880). A paired Wilcoxon test found no significant difference across groups in the proportion of highly visual words (*W* = 78, *p* = .632).

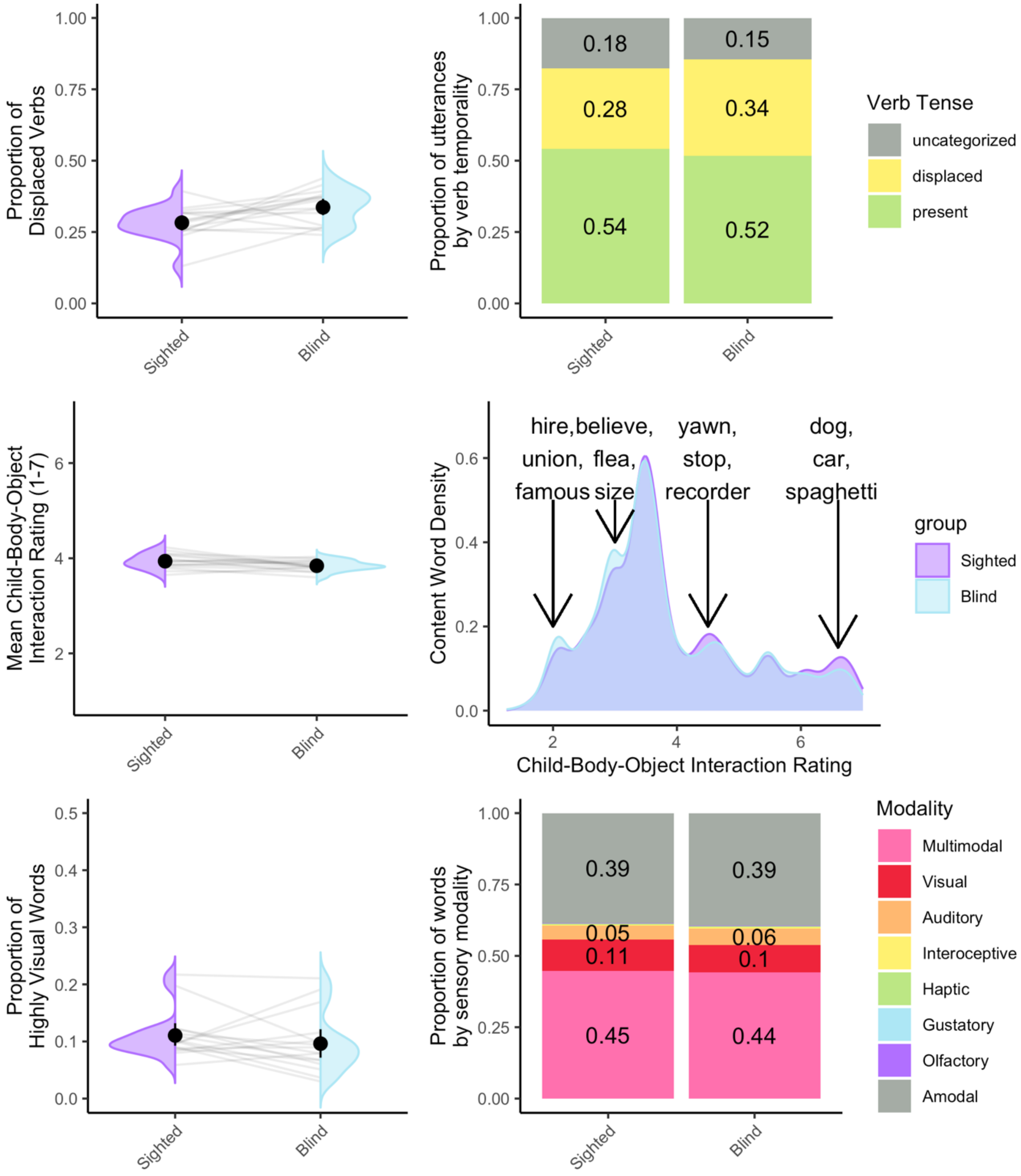

Figure 20: Left col: Comparing proportion of temporally displaced verbs (top), mean Child- Body-Object-Interaction rating (middle), and proportion of highly visual words (bottom). Each dot represents one child's recording, with black dot and whiskers showing means and standard errors. Right col: Full distribution of verb types (top), Child-Body-Object Interaction ratings (middle), and sensory modality (bottom) by group, collapsing across participants.

Table 20: Summary of analyses over language input variables.

Variable	**Test**	**Direction**	**Mean$_{Blind}$**	**Mean$_{Sighted}$**	***p* value**	**Survives Correction?**
Adult Word Count	Paired Wilcoxon test	Blind ~ Sighted	1171 words/hr	1033 words/hour	.243	
Manual Word Count	Paired t-test	Blind ~ Sighted	2065 words/hr	2409 words/hour	.255	
Conversational Turn Count	Paired Wilcoxon test	Blind ~ Sighted	33 turns/hr	43 turns/hour	.952	
Prop. Child Directed Speech	Paired t-test	Blind ~ Sighted	0.57	0.57	.096	
Type-Token Ratio	Paired t-test	Blind > Sighted	0.65	0.62	.040	*
Mean Length of Utterance	Paired t-test	Blind > Sighted	5.65 morphemes	5.04	.024	*
Prop. Displaced	Paired t-test	Blind > Sighted	0.34	0.28	.014	*
Child-Body-Object Interaction	Kolmogorov-Smirnow test	Blind < Sighted	3.84 / 7	3.95 / 7	< .001	*
Prop. Visual	Paired Wilcoxon test	Blind ~ Sighted	0.1	0.11	.632	

5.4 Discussion

This study, which contains more blind participants than prior research alongside a carefully peer-matched sighted sample, measured language input to young blind children and their sighted peers, using the LENA audio recorder. We found that along the dimensions of quantity and interaction, parents talk similarly to blind and sighted children, with differences in linguistic and conceptual content of the input. We discuss each of these results further below.

5.4.1 Quantity

Across two measures of language input quantity, one estimated from the full sixteen hour recording (Adult Word Count) and one precisely measured from a 30-minute window of that day (Manual Word Count), blind and sighted children were exposed to similar amounts of speech in the home. Quantity was highly variable *within* groups, but we found no evidence for *between* group differences in input quantity. This runs counter to two folk accounts of language input to blind children: 1) that sighted parents of blind children might talk *less* because they don't share visual common ground with their children; 2) that parents of blind children might talk *more* to compensate for their children's lack of visual input. Instead, we find a similar quantity of speech across groups.

5.4.2 Interaction

We quantified interaction in two ways: through the LENA-estimated conversational turn count and through the proportion of child-directed speech in our manual annotations. Again, we found no differences across groups in the amount of parent-child interaction. This finding contrasts with previous research; other studies report *less* interaction in dyads where the child is blind (Andersen et al., 1993; Grumi et al., 2021; Kekelis & Andersen, 1984; Moore & McConachie, 1994; Perez-Pereira & Conti-Ramsden, 1999; Pérez-Pereira & Conti-Ramsden, 2001; Preisler, 1991; Rowland, 1984).

Using a non-visual sampling method (i.e., our audio recordings) might provide a different, more naturalistic perspective on parent-child interactions, particularly in this population. For one thing, many prior studies (e.g., Kekelis & Andersen, 1984; Moore & McConachie, 1994; Pérez-Pereira & Conti-Ramsden, 2001; Preisler, 1991) involve videorecordings in the child's home, with the researcher present. Like other young children, blind children distinguish between familiar individuals and strangers, and react with trepidation to the presence of a stranger (Fraiberg, 1975; McRae, 2002); for blind children, this reaction may involve "quieting", wherein children cease speaking or vocalizing when they hear a new voice in the home (Fraiberg, 1975; McRae, 2002). By having a researcher present during the recordings[9], prior research may have artificially suppressed blind children's initiation of interactions. Even naturalistic observer-free videorecordings appear to inflate aspects of parental input, relative to daylong audio recordings (Bergelson et al., 2019). In these cases, the video camera acts as an observer itself, making participants aware of its presence, limiting participants' mobility, and therefore shrinking the pragmatic scope of possible interactions. Together, these factors could explain why past parent-child interaction research finds that blind children initiate fewer interactions (Andersen et al., 1993; Dote-Kwan, 1995; Kekelis & Andersen, 1984; Moore & McConachie, 1994; Tröster & Brambring, 1992), that parents do most of the talking (Andersen et al., 1993; Kekelis & Andersen, 1984), and that there is overall

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[9] Fraiberg (1975) writes "these fear and avoidance behaviors appear even though the observer, a twice-monthly visitor, is not, strictly speaking, a stranger." (pg. 323).

less interaction (Nagayoshi et al., 2017; Rogers & Puchalski, 1984; Rowland, 1984; Tröster & Brambring, 1992).

Additionally, a common focus in earlier interaction literature is to measure visual cues of interaction, such as shared gaze or attentiveness to facial expressions (Baird et al., 1997; Preisler, 1991; Rogers & Puchalski, 1984). We can't help but wonder: are visual markers of social interaction the right yardstick to measure blind children against? In line with MacLeod and Demers (2023), perhaps the field should move away from sighted indicators of interaction "quality", and instead situate blind children's interactions within their own developmental niche, one that may be better captured with auditory- or tactile-focused measures.

5.4.3 Linguistic Features

Along the linguistic dimension, we measured type-token ratio and mean length of utterance. Parents of children with disabilities (including parents of blind children! e.g., Chernyak, n.d.; FamilyConnect, n.d.) are often advised to use shorter, simpler sentences with their children; correspondingly, previous work finds that parents of children with disabilities tend to find that parents *do* use shorter, simpler utterances (e.g., Down syndrome, Dirks et al., 2020; hearing loss, Lorang et al., 2020). We therefore expected to observe shorter utterances and less lexical diversity. Instead, type-token ratio and MLU were higher for blind children, suggesting that blind children are exposed to more lexically and morphosyntactically complex speech. Returning to the potential impact on children, evidence suggests that (contrary to the advice often given to parents), longer, more complex utterances are associated with better child language outcomes in both typically-developing children (Hoff & Naigles, 2002) and children with cognitive differences (Sandbank & Yoder, 2016). And similarly, higher lexical diversity is associated with larger vocabulary (Anderson et al., 2021; Hsu et al., 2017; Huttenlocher et al., 2010; Rowe, 2012; Weizman & Snow, 2001). It seems that advice to simplify speech to blind children, while well-intentioned, is unnecessary.

5.4.4 Conceptual Features

Although there are many potential ways to measure the conceptual features of language, we chose to capture *here-and-now*-ness by measuring the proportion of temporally displaced verbs, the distribution of high vs. low child-body-object interaction ratings for content words, and the proportion of highly visual words. We found that blind children heard more temporally displaced verbs and their content words were distributed slightly more to the “not-interactable” end of the child-body-object interaction scale. Though blind and sighted participants were exposed to a similar proportion of highly visual words, the referents of these words are by definition, inaccessible to the blind participants. Taken together, our conceptual results suggest that blind children’s input is *less* focused on their *here-and-now*.

The extent to which blind children’s language input is centered on the *here-and-now* has been contested in the literature (Andersen et al., 1993; Campbell, 2003; Kekelis & Andersen, 1984; Moore & McConachie, 1994; Urwin, 1984). This aspect of language input is of particular interest because early reports suggest that blind children’s own use of decontextualized language develops later than sighted children's[10] (Bigelow, 1990; Urwin, 1984). Could this be related to an absence of decontextualized language in the input? Our sample says no: we find that blind children's input contains *more* decontextualized language. Because children have less access to immediate visual cues, caregivers might more frequently refer to past or future events to engage with their child. To illustrate, while riding on a train, instead of describing the scenery passing outside the window, parents may choose to talk about what happened earlier in the day or their plans upon home. Without further information about the social and perceptual context, it is difficult to determine the communicative function of the differences we find in conceptual features we find or how they might explain differences in children's decontextualized language use. As more dense annotation becomes available, we can explore the social and environmental contexts of conceptual information as it unfolds across discourse.

5.4.4 Patterns in Language Input

Before synthesizing an account of these differences, we wish to highlight again how much variability there is *within* groups and how much consistency there is *between* groups. One could imagine a world in which the language environments of blind and sighted children are radically different from each other. Our data do not support that

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[10] Perhaps relatedly, object permanence and related skills may be delayed in blind children (Rogers & Puchalski, 1988).

hypothesis. Rather, we find similarity in quantity and interaction, alongside modest differences in linguistic and conceptual properties. This is worth emphasizing and re-emphasizing: across developmental contexts, including, as we show here, visual experience, children's language input is resoundingly similar (Bergelson et al., 2022). That said, when we zoom into more fine-grained aspects of the input, we find that blind children's language environments contain longer utterances, more lexical diversity, more temporal displacement, and content words that are harder for children to interact with. Together, these features suggest that blind toddlers' input is more similar to speech directed towards older children or adults (Rowe, 2012; Snow, 1972) than sighted toddlers'. We cannot singularly attribute this to differences in addressee: our manual annotations indicate a similar proportion of child-.vs.adult-directed speech across the two groups.

5.4.5 Connecting to Language Outcomes

This may be part of the reason why language delays are common in blind toddlers, but often resolved in older childhood (Landau & Gleitman, 1985). If direct sensory access to referents provides an initial "brute force" mechanism for mapping words onto meanings (e.g., shared gaze, pointing, visual perception of referents), it may take longer for blind children to acquire the first few words. By hypothesis, once this initial seed of lexical knowledge is acquired, blind children and sighted children alike are able to use more abstract and linguistic features as cues, and learning can proceed more rapidly thereafter (Babineau et al., 2021; Campbell & Bergelson, 2022b). It could be precisely this additional linguistic input complexity which aids blind children in acquiring semantic knowledge later in development, once the first words are acquired. Under this theory, language input interventions or specific compensatory strategies for input to blind children become unnecessary for cognitively-typical blind children: the rich information in the language input and the infants' own learning capacity are plenty sufficient for acquiring language. Testing this prediction awaits further research.

5.4.6 Conclusion

In summary, our study compared language input in homes of 15 blind and 15 sighted infants. We found that both groups received similar quantities of adult speech and had similar levels of interaction. However, blind children were exposed to longer utterances and more decontextualized language, suggesting that they are being exposed to a rich and complex linguistic environment that differs from the language input of sighted children. Our study does not imply that parents should change their communication styles, but rather highlights the unique language experiences of blind children. Future research should investigate how these input differences impact the language development and cognitive abilities of blind and sighted children alike.

6. General Discussion

In the preceding chapters, we examined how language input and perception are intertwined in the early experiences of children born deaf or blind and how these experiences shape lexical development. In Chapter 2 (Campbell & Bergelson, 2022a), we studied a diverse sample of Deaf/Hard-of-Hearing children receiving early intervention in North Carolina. We found that this sample showed spoken language vocabulary delays relative to hearing peers, and determined that there is much room for improvement in rates of early diagnosis and intervention. These delays in vocabulary and early support services were predicted by an overlapping subset of hearing-, health-, and home-related variables, which reflected both dimensions that are immutable, and those that clinicians and caretakers can potentially affect. While several of the relationships shown here are somewhat intuitive (e.g., deaf children born premature are more likely to have health issues), this chapter serves to highlight the intricate interconnectedness of the variables influencing deaf children's vocabulary production. For instance, children with more severe hearing loss generally have larger spoken vocabulary delays (Ching et al., 2013; de Diego-Lázaro et al., 2018; Vohr et al., 2011; Yoshinaga-Itano et al., 2017). But more severe hearing loss is also associated with earlier diagnosis and with use of hearing aids or cochlear implants (E. E. Campbell & Bergelson, 2022a), each of which are associated with *smaller* vocabulary delays (Apuzzo & Yoshinaga-Itano, 1995; Campbell & Bergelson, 2022; Kennedy et al., 2006; Robinshaw, 1995; White & White, 1987; Yoshinaga-Itano et al., 1998, 2018). The results of this chapter urge researchers and clinicians to avoid thinking of any of these factors as isolated, but rather as fitting into a constellation of factors with potential influences on language development.

In Chapter 3 (Campbell, Casillas, & Bergelson, *under review*), we asked whether access to vision influences the trajectory and composition of the early lexicon. We found that on average, blind children showed a roughly half-year vocabulary delay relative to sighted children, amid considerable variability. These results, gleaned from 40 full-term, congenitally-blind children, help resolve a longstanding debate in the field (Bigelow, 1990; Landau & Gleitman, 1985; McConachie, 1990; Mulford, 1988; Nelson, 1973) over whether blind children exhibit early vocabulary delays. However, the content of blind and sighted children's vocabulary was statistically indistinguishable in word length, part of speech, semantic category, concreteness, interactiveness, and perceptual modality. At a finer-grained level, we also found that words' perceptual properties intersect with children's perceptual abilities: the strength of words' visual associations influenced sighted children's (but not blind children's) likelihood of word production, and the multimodalness of visual words mattered for blind (but not sighted) children. Our findings suggest that while an absence of visual input may initially make vocabulary development more difficult, the content of the early productive vocabulary is *largely* resilient to differences in perceptual access, with the exception of words whose referents are *uniquely imperceptible to children with sensory impairments*.

Chapter 4 looked across populations, asking how differential access to perceptual and linguistic information influences young children's production of words (Campbell, Davis, Cooke, Houston, Caselli, & Bergelson, *under review*). Here, we measured the production of visual, auditory, and abstract words by young deaf, blind, and typically-hearing/sighted children learning language either from birth or at a months-long delay; to our knowledge, this study is the first to leverage this diverse range of populations. We found that children can produce words in the imperceptible modality even before their second birthday. However, words in the imperceptible modality are less likely to be produced: blind children are less likely than sighted peers to say highly visual words like "blue" or "see", and deaf signing children are less likely to produce auditory signs like HEAR or RADIO. Additionally, convergent with prior research (e.g., Caselli et al., 2021; Nicholas & Geers, 2007), in both spoken English and ASL, children who receive delayed access to language input were less likely to produce words overall. These results demonstrate how access to perceptual and language information impacts the words that enter children's early vocabulary.

Chapter 5 attempted to tease apart language input and perceptual experience, by measuring properties of the language environments of blind and sighted children. This study builds on prior research examining language input to blind children (e.g.,Andersen et al., 1984, 1993; Dote-Kwan, 1995; Kekelis & Andersen, 1984; Landau & Gleitman, 1985; Moore & McConachie, 1994; Nagayoshi et al., 2017; Rogers & Puchalski, 1984; Rowland, 1984; Tröster & Brambring, 1992). Our results showed that both groups received similar speech quantity. *Contrary* to previous research, which asserted that parents of blind children interact *less* with their children, we found similar levels of interaction across groups for both of our measures of interaction (proportion of child-directed speech and number of conversational turns). Fine-grained analysis also revealed that blind children's language environments contained more lexical diversity, longer utterances, more temporal displacement, and content words that are harder for children to interact with, suggesting more complex input than sighted children are exposed to. These results diverge from the previous literature, which reported less interaction (Andersen et al., 1984, 1993; Dote-Kwan, 1995; Kekelis & Andersen, 1984; V. Moore & McConachie, 1994; Nagayoshi et al., 2017; Rogers & Puchalski, 1984; Rowland, 1984; Tröster & Brambring, 1992) and more here-and-now talk (though this dimension has been more disputed, Andersen et al., 1993; Campbell, 2003; Kekelis & Andersen, 1984; Moore & McConachie, 1994; Urwin, 1984). The findings of this chapter challenge the previous literature claiming that blind children's language input places them at a disadvantage and instead suggests that blind children receive linguistically and conceptually rich language input that can support their language development.

Taken together, these studies highlight the importance of accessible language input, the resilience of language acquisition to differences in perception, and the dynamic interplay between sensory perception, cognitive abilities, and the acquisition of linguistic knowledge. To contextualize these results, we first return to the broader picture of early vocabulary acquisition, and then consider how different forms of input may fit into this process.

6.1 Returning to the bigger picture: How do children begin learning language?

Children with typical hearing/vision learn their first words through linguistic, social, and perceptual cues, and everyday interactions (Bohn et al., 2021; Fisher & Gleitman, 2002; Smith, 2000; Tomasello, 2001). Cross-linguistically, for both comprehension and production, children's first words tend to be concrete, highly-frequent nouns with stable perceptual features, like "foot" and "banana" (Benedict, 1979; Bergelson & Aslin, 2017; Bergelson & Swingley, 2013, 2015; Frank et al., 2021; Kartushina & Mayor, 2019; Tincoff & Jusczyk, 1999, 2012). As children mature and encounter more language input and everyday experience, they are able to make increasingly complex inferences about word meaning (Bergelson, 2020; Bohn et al., 2021; Meylan & Bergelson, 2022). However, if high word frequency and perceptual consistency are necessary for initializing the lexicon, this process may be disrupted for children with sensory impairments; in this dissertation, we measured this via the productive vocabularies of young children born deaf or blind.

6.2 How does input affect early lexical development?

6.2.1 Language input

In Chapter 2, we saw that children with less access to language (more severe hearing loss in spoken language environments) had larger vocabulary delays than children with more auditory access to language. Similarly, in Chapter 4, we observed that children who receive delayed access to language (spoken or signed) are less likely to produce the words in our study. These results underscore the importance of language access that is 1) available from early infancy, and 2) fully accessible.

But we also see that the input changes as a function of child abilities. For example, the Chapter 2 data show that parents are more likely to offer a Total Communication approach (a mix of spoken language, lipreading, isolated signs, and gestures) to children who have a developmental delay. Chapter 5 indicates that parents may alter the linguistic and conceptual content of their speech based on their children's visual abilities. These input differences may be adaptive, offering children input that is somehow more useful or accessible to them. Unfortunately, our data cannot connect these differences to children's outcomes, but future research could connect these dots by charting children's later language outcomes as a function of properties of their language input.

6.2.3 Perceptual input

6.2.3.1 Deafness

The effects of visual and auditory input are not symmetrical. Deafness, by way of language input, impedes spoken language development. For deaf children in a spoken language household, the speech signal is inaccessible, so there are many fewer linguistic tokens, and thus deaf children without sign language access or some form of amplification tend to experience language delays (e.g., Svirsky et al., 2000). However, deaf children who receive early access to a signed language typically achieve language proficiency (Caselli et al., 2021; Mayberry & Squires, 2006). Rather than pointing to an importance of auditory input, this pattern of results points to an importance of linguistic input. The necessity of language input speaks to an age-old question in language development: how much linguistic knowledge are children born with, and how much must they acquire through experience (Piattelli-Palmarini, 1980)? The graded effects of language access on vocabulary delay, shown here in Chapters 2 and 4 and convergent with prior work point to an important role of language experience in the tale of acquisition.

6.2.3.2 Blindness

Blindness, by contrast, seems to initially impede lexical development by reducing referential transparency; in the absence of vision, it is harder to link word labels to objects and events in the environment. For blind children, this results in an initial vocabulary delay, as shown in Chapter 3. But as we know from data from older blind children and adults (Loiotile et al., 2020; Röder et al., 2000, 2003), blind learners do later catch up and show fluency that matches (and on some measures, exceeds) that of their sighted peers (Loiotile et al., 2020; Röder et al., 2003).

One theory that could explain this pattern of language acquisition is the semantic seed hypothesis (Babineau et al., 2021; Christophe, 2016). This theory builds onto the extensive syntactic bootstrapping literature (Babineau et al., 2022; Barbir et al., 2023; Brusini et al., 2016; Fisher et al., 2010, 2020; Gleitman, 1990; Jin & Fisher, 2014; Naigles, 1990), whereby children can use the syntactic context to learn novel words. For example, a sentence like "he *blicked* the ball to her" constrains the meaning of "blicked" to mean an action that can be done to a ball to another person. The semantic seed hypothesis adds that in order to make use of syntactic structure, children need to already know the meanings of some words.

We hypothesize that blind and sighted children acquire their first words, the semantic seed, by the same mechanism: children observe associations between a word label and a perceptual experience (seeing a dog, feeling a ball), which may simply be harder to do without vision. As discussed in Chapter 1, many cues for word meaning are visual (eye gaze, pointing, seeing objects), and instances of perception-label co-occurrence in *non*-visual modalities may be more challenging for word learning. That is to say, relative to visual experiences, sounds and smells are more transient, and tastes and tactile experience are less omnipresent, potentially making non-visual perceptual experiences harder to map labels onto.

After passing this initial hurdle, how do children catch up? Syntactic bootstrapping and distributional semantics are two mechanisms by which children can use the structure of language to infer word meaning. Per the semantic seed hypothesis, these mechanisms require some initial lexical knowledge, which may explain blind children's unique vocabulary trajectory. Notably, this proposed explanation is not qualitatively different from how we think sighted children learn words – it just differs in the relative weight of each strategy.

Despite these differences in vocabulary trajectories, in Chapter 3, we saw that the content of children's early vocabulary does not vary much based on children's visual experience. The exception to this, as shown in Chapter 4, may be imperceptible words. By hypothesis, in the absence of a perceptible referent, words may not enter the lexicon until children can draw on other strategies (e.g., distributional semantics, syntactic bootstrapping), which may await the development of greater linguistic competence.

Summarizing across these findings, blindness and deafness both shape the course of spoken language development, albeit by different mechanisms. In the case of deafness, spoken word labels are inaccessible. In the case of blindness, referents and certain social cues to word meaning cannot be perceived visually. When the language input remains inaccessible, delays are persistent, but when referents are visually inaccessible, delays are overcome later in childhood. In both cases, words with imperceptible referents are most vulnerable.

6.3 Open Questions

6.3.1 How do children represent the meanings of imperceptible words?

In Chapter 4, blind and deaf children were observed to produce words like blue and hear before age 2, but what do these words actually mean to them? Our data do not directly offer answers to this question, but previous literature can lend some insight. Here, we focus on the case of blind children for illustration. Blind children's semantic representation of visual words has been speculated upon for decades, if not centuries.

Locke (1894) reasoned that no amount of instruction would enable a blind individual to understand light and color. Perhaps, he postulated, blind individuals could learn associations (e.g., that daffodils are yellow) or wave theory (e.g., that light with a wavelength of 560-590 nanometers is perceived as yellow), but they would be unable to comprehend the perceptual experience of a yellow daffodil (Locke, 1984). Hume, (1753) posited that imagination is constructed from previously encountered stimuli. Thus, he reasoned, a congenitally blind individual would be unable to imagine color, and a congenitally Deaf individual would be unable to imagine sound, having never experienced those sensations. Cutsforth (1932) brazenly asserted that because blind children do not physically perceive the referents of visual words, their representations are rooted in “unreality”, their words meaningless “verbalism”s.

More recent evidence disputes these claims: Blind adults demonstrate nuanced knowledge of both literal and figurative meanings of visual words (Bedny et al., 2019; Kim et al., 2019, 2020; Minervino et al., 2018; Saysani et al., 2021; Striem-Amit et al., 2018). It is unclear, however, whether this semantic sophistication is present from the earliest stages of word production. In Landau & Gleitman’s seminal text on language acquisition in blind children (1985), they charted the development of one subject – Kelli’s – use of visual words. Until age four, when asked “Give me the green [object]” Kelli would hand the experiment an object and say (incorrectly) “Here’s the green one,” without any basis for determining object color. By 4;6 years, when asked to retrieve an object based on color, Kelli would instead ask a sighted adult for help selecting the correct object. This suggests that around preschool age, children develop social-cognitive abilities that enrich their representations, by recognizing that sighted individuals experience visual phenomena differently. By hypothesis, therefore, visual words may initially enter the lexicon as abstract words, and as children develop more mature social cognition, the meanings of visual words may evolve to "a physical phenomenon that other people can perceive but I cannot." Charting blind children's use of blind words across a broad age range (a la Landau & Gleitman, 1985), alongside measures of social reasoning (e.g., Bigelow, 1988; Birch et al., 2017; Gweon et al., 2010; McAlpine & Moore, 1995; Teufel et al., 2013) could help illuminate which skills serve as the foundation for meaning in these unique cases.

6.3.2 How do sighted or hearing parents talk about visual or auditory words with their blind or deaf children?

Unlike deaf children of deaf parents (who we studied as a control case in Chapter 4), the majority of blind or deaf children are born to typically-sighted/hearing parents. Given that parents' perceptual experiences differ from those of their children, how do parents use words which refer to the inaccessible domain? In Chapter 5, we observed that highly visual words constitute roughly 10% of the input for both blind and sighted children. Unfortunately, at the current granularity of our analysis, we do not know much about the communicative context of these words. A few possibilities come to mind: On the one hand, it's possible that the use of highly visual or auditory words is identical across populations; parents don't alter their speech in this way. Given that, as we saw in Chapter 5, language input to blind and sighted children is similar in many ways (i.e., quantity, interaction), this possibility is plausible. On the other hand, sighted infants of blind mothers can be observed to tailor their interactions to the visual abilities of their parent (Senju et al., 2013). And likewise, our data from the language recordings revealed differences in the conceptual content of speech to blind and sighted children, so the context of use of highly visual/auditory words may differ as well. For instance, naturalistic speech to typically-sighted/hearing children more often contains atypical descriptions (e.g., "Clifford the Big Red Dog") than prototypical descriptions ("I want a yellow banana" vs. "I want a banana") (Bergey et al., 2020). This could be because speakers tend to omit redundant information, and "yellow banana" would often be redundant with perceptual information. Because color information (or sound information for deaf children) would not be redundant with perceptual information available to the child, might parents of blind children use more prototypical description?

If parents do provide more informative description for the affected modality, this tailoring could be how children with sensory impairments learn prototypical perceptual information about the affected modality. If parents of children with sensory impairments do *not* tailor the input, then given the overrepresentation of *atypical* perceptual descriptors (Bergey et al., 2020), children with sensory impairments must be able to draw on linguistic structure to learn the prototypical information. As additional annotation on these recordings becomes available, we can hopefully learn more about how caregivers use these words in conversation.

7. Conclusions

This dissertation explored how varying access to information in the world (through sight, sound, or language) shapes children's language development. The results of these studies are of course relevant to language interventions for children born deaf or blind, but are also applicable to the broader population of language learners. **Accessible language input is crucial:** without early access to language input, children struggle to learn language**. Accessible referents are helpful, but their absence is work-around-able:** without visual access to referents, blind children show initial lexical delays but later catch up**. Children are flexible, resourceful, and capable.** These findings contribute to our understanding of the fundamental processes involved in early language development, shedding light on the complex relationships between sensory perception, cognitive abilities, and the acquisition of linguistic knowledge.

References

Abreu, R. A., Adriatico, T., & DePierro, A. (2011). ¿QUÉ PASA?: "What's Happening" in Overcoming Barriers to Serving Bilingual Children? *The ASHA Leader*, *16*(13). https://doi.org/10.1044/leader.FTR2.16132011.12

Allport, D. A. (1985). Distributed Memory, Modular Subsystems and Dysphasia. In *Current perspectives in dysphasia* (pp. 207–244). Churchill Livingstone.

Ambrose, S. E., Walker, E. A., Unflat-Berry, L. M., Oleson, J. J., & Moeller, M. P. (2015). Quantity and Quality of Caregivers' Linguistic Input to 18-month and 3-year-old Children who are Hard of Hearing. *Ear and Hearing*, *36*(0 1), 48S-59S. https://doi.org/10.1097/AUD.0000000000000209

Andersen, E. S., Dunlea, A., & Kekelis, L. (1993). The impact of input: Language acquisition in the visually impaired. *First Language*, *13*(37), 23–49. https://doi.org/10.1177/014272379301303703

Andersen, E. S., Dunlea, A., & Kekelis, L. S. (1984). Blind Children's Language: Resolving Some Differences. *Journal of Child Language*, *11*(3), 645–664. https://doi.org/10.1017/s0305000900006000

Anderson, N. J., Graham, S. A., Prime, H., Jenkins, J. M., & Madigan, S. (2021). Linking Quality and Quantity of Parental Linguistic Input to Child Language Skills: A Meta-Analysis. *Child Development*, *92*(2), 484–501. https://doi.org/10.1111/cdev.13508

Apuzzo, M.-R. L., & Yoshinaga-Itano, C. (1995). Early Identification of Infants with Significant Hearing Loss and the Minnesota Child Development Inventory. *Seminars in Hearing*, *16*(2).

Babineau, M., de Carvalho, A., Trueswell, J., & Christophe, A. (2021). Familiar words can serve as a semantic seed for syntactic bootstrapping. *Developmental Science*, *24*(1), e13010. https://doi.org/10.1111/desc.13010

Babineau, M., Havron, N., Dautriche, I., de Carvalho, A., & Christophe, A. (2022). Learning to predict and predicting to learn: Before and beyond the syntactic bootstrapper. *Language Acquisition*, *0*(0), 1–24. https://doi.org/10.1080/10489223.2022.2078211

Baird, S. M., Mayfield, P., & Baker, P. (1997). Mothers' Interpretations of the Behavior of Their Infants with Visual and Other Impairments during Interactions. *Journal of*

Visual Impairment & Blindness, *91*(5), 467–483. https://doi.org/10.1177/0145482X9709100507

Barbir, M., Babineau, M. J., Fiévet, A.-C., & Christophe, A. (2023). Rapid infant learning of syntactic–semantic links. *Proceedings of the National Academy of Sciences*, *120*(1), e2209153119. https://doi.org/10.1073/pnas.2209153119

Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences*, *22*(4), 637–660.

Bates, E., Marchman, V., Thal, D., Fenson, L., Dale, P., Reznick, J. S., Reilly, J., & Hartung, J. (1994). Developmental and stylistic variation in the composition of early vocabulary. *Journal of Child Language*, *21*(1), 85–123. https://doi.org/10.1017/S0305000900008680

Bedny, M., Koster-Hale, J., Elli, G., Yazzolino, L., & Saxe, R. (2019). There's more to "sparkle" than meets the eye: Knowledge of vision and light verbs among congenitally blind and sighted individuals. *Cognition*, *189*, 105–115. https://doi.org/10.1016/j.cognition.2019.03.017

Bellagamba, F., Borghi, A. M., Mazzuca, C., Pecora, G., Ferrara, F., & Fogel, A. (2022). Abstractness emerges progressively over the second year of life. *Scientific Reports*, *12*(1), Article 1. https://doi.org/10.1038/s41598-022-25426-5

Benedict, H. (1979). Early lexical development: Comprehension and production*. *Journal of Child Language*, *6*(2), 183–200. https://doi.org/10.1017/S0305000900002245

Benjamini, Y., & Hochberg, Y. (1995). Controlling the False Discovery Rate: A Practical and Powerful Approach to Multiple Testing. *Journal of the Royal Statistical Society. Series B (Methodological)*, *57*(1), 289–300.

Bergelson, E. (2020). The Comprehension Boost in Early Word Learning: Older Infants Are Better Learners. *Child Development Perspectives*, *14*(3), 142–149. https://doi.org/10.1111/cdep.12373

Bergelson, E., Amatuni, A., Dailey, S., Koorathota, S., & Tor, S. (2019). Day by day, hour by hour: Naturalistic language input to infants. *Developmental Science*, *22*(1), e12715. https://doi.org/10.1111/desc.12715

Bergelson, E., & Aslin, R. N. (2017). Nature and origins of the lexicon in 6-mo-olds. *Proceedings of the National Academy of Sciences*, *114*(49), 12916–12921. https://doi.org/10.1073/pnas.1712966114

Bergelson, E., Soderstrom, M., Schwarz, I.-C., Rowland, C., Ramirez-Esparza, N., Hamrick, L., Marklund, E., Kalashnikova, M., Guez, A., & Casillas, M. (2022). *Everyday language input and production in 1001 children from 6 continents*.

Bergelson, E., & Swingley, D. (2012). At 6-9 months, human infants know the meanings of many common nouns. *Proceedings of the National Academy of Sciences*, *109*(9), 3253–3258. https://doi.org/10.1073/pnas.1113380109

Bergelson, E., & Swingley, D. (2013). The acquisition of abstract words by young infants. *Cognition*, *127*(3), 391–397. https://doi.org/10.1016/j.cognition.2013.02.011

Bergelson, E., & Swingley, D. (2015). Early Word Comprehension in Infants: Replication and Extension: Language Learning and Development: Vol 11, No 4. *Language Learning and Development*, *11*(4), 369–380. https://doi.org/10.1080/15475441.2014.979387

Bergey, C., Morris, B., & Yurovsky, D. (2020). *Children hear more about what is atypical than what is typical*. PsyArXiv. https://doi.org/10.31234/osf.io/5wvu8

Bernstein Ratner, N. (1984). Patterns of vowel modification in mother–child speech. *Journal of Child Language*, *11*, 557–578.

Bigelow, A. (1986). The development of reaching in blind children. *British Journal of Developmental Psychology*, *4*(4), 355–366. https://doi.org/10.1111/j.2044-835X.1986.tb01031.x

Bigelow, A. (1987). Early words of blind children. *Journal of Child Language*, *14*(1), 47–56. https://doi.org/10.1017/S0305000900012721

Bigelow, A. (1988). Blind Children's Concepts of how People See. *Journal of Visual Impairment & Blindness*, *82*(2), 65–68. https://doi.org/10.1177/0145482X8808200208

Bigelow, A. (1990). Relationship between the Development of Language and Thought in Young Blind Children. *Journal of Visual Impairment & Blindness*, *84*(8), 414–419. https://doi.org/10.1177/0145482X9008400805

Bigelow, A. (2003). Development of joint attention in blind infants. *Development and Psychopathology*, *15*, 259–275. https://doi.org/10.1017/S0954579403000142

Birch, S. A. J., Li, V., Haddock, T., Ghrear, S. E., Brosseau-Liard, P., Baimel, A., & Whyte, M. (2017). Chapter Six - Perspectives on Perspective Taking: How Children Think About the Minds of Others. In J. B. Benson (Ed.), *Advances in Child Development* *and Behavior* (Vol. 52, pp. 185–226). JAI. https://doi.org/10.1016/bs.acdb.2016.10.005

Blackorby, J., & Knokey, A.-M. (2006). *A National Profile of Students with Hearing Impairments in Elementary and Middle School: A Special Topic Report from the Special Education Elementary Longitudinal Study*. 30.

Blair, J. C., Peterson, M. E., & Viehweg, S. H. (1985). The Effects of Mild Sensorineural Hearing Loss on Academic Performance of Young School-Age Children. *Volta Review*, *87*(2), 87–93.

Bohn, M., Tessler, M. H., Merrick, M., & Frank, M. C. (2021). How young children integrate information sources to infer the meaning of words. *Nature Human Behaviour*, *5*(8), 1046–1054. https://doi.org/10.1038/s41562-021-01145-1

Boothroyd, A., & Eran, O. (1994). Auditory Speech Perception Capacity of Child Implant Users Expressed as Equivalent Hearing Loss. *Volta Review*, *96*(5), 151–167.

Borchert, M., & Garcia-Filion, P. (2008). The syndrome of optic nerve hypoplasia. *Current Neurology and Neuroscience Reports*, *8*(5), 395–403. https://doi.org/10.1007/s11910-008-0061-7

Borghi, A. M., & Binkofski, F. (2014). *Words as social tools: An embodied view on abstract concepts* (1st ed.). Springer. https://link.springer.com/book/10.1007/978-1-4614-9539-0

Bottini, R., Morucci, P., D'Urso, A., Collignon, O., & Crepaldi, D. (2022). The concreteness advantage in lexical decision does not depend on perceptual simulations. *Journal of Experimental Psychology: General*, *151*(3), 731–738. https://doi.org/10.1037/xge0001090

Boudreault, P., & Mayberry, R. I. (2006). Grammatical processing in American Sign Language: Age of first-language acquisition effects in relation to syntactic structure. *Language and Cognitive Processes*, *21*(5), 608–635. https://doi.org/10.1080/01690960500139363

Brambring, M. (2007). Divergent Development of Verbal Skills in Children who are Blind or Sighted. *Journal of Visual Impairment & Blindness*, *101*(12), 749–762. https://doi.org/10.1177/0145482X0710101205

Bratt, J., Harmon, J., & Learning, B. F. & W. P. G. L. D. M. (2022). *morphemepiece: Morpheme Tokenization* (1.2.3). https://CRAN.R-project.org/package=morphemepiece

Bremner, A. J., Lewkowicz, D. J., & Spence, C. (2012). *Multisensory Development*. OUP Oxford.

Brooks, R., & Meltzoff, A. N. (2008). Infant gaze following and pointing predict accelerated vocabulary growth through two years of age: A longitudinal, growth curve modeling study*. *Journal of Child Language*, *35*(1), 207–220. https://doi.org/10.1017/S030500090700829X

Brugman, H., & Russel, A. (2009). Annotating Multimedia / Multi-modal resources with ELAN. *Proceedings of the Fourth International Conference on Language Resources and Evaluation*.

Brusini, P., de Carvalho, A., Dautriche, I., Gutman, A., Cauvet, E., Millotte, S., Amsili, P., & Christophe, A. (2016). *Bootstrapping lexical and syntactic acquisition*.

Brysbaert, M., Warriner, A. B., & Kuperman, V. (2014). Concreteness ratings for 40 thousand generally known English word lemmas. *Behavior Research Methods*, *46*(3), 904–911. https://doi.org/10.3758/s13428-013-0403-5

Bulut, O., & Desjardins, C. D. (2020). *Profile Analysis of Multivariate Data: A Brief Introduction to the profileR Package*. PsyArXiv. https://doi.org/10.31234/osf.io/sgy8m

Busch, T., Sangen, A., Vanpoucke, F., & van Wieringen, A. (2018). Correlation and agreement between Language ENvironment Analysis (LENA™) and manual transcription for Dutch natural language recordings. *Behavior Research Methods*, *50*(5), 1921–1932. https://doi.org/10.3758/s13428-017-0960-0

Byers-Heinlein, K., Fennell, C. T., & Werker, J. F. (2013). The development of associative word learning in monolingual and bilingual infants. *Bilingualism: Language and Cognition*, *16*(1), 198–205. https://doi.org/10.1017/S1366728912000417

Caballero, A., Muñoz, K., White, K., Nelson, L., Domenech-Rodriguez, M., & Twohig, M. (2017). Pediatric Hearing Aid Management: Challenges among Hispanic Families. *Journal of the American Academy of Audiology*, *28*(8), 718–730. https://doi.org/10.3766/jaaa.16079

Campbell, E. E., & Bergelson, E. (2022a). Characterizing North Carolina’s Deaf and Hard of Hearing Infants and Toddlers: Predictors of Vocabulary, Diagnosis, and Intervention. *Journal of Speech, Language, and Hearing Research*, *65*(5), 1894–1905. https://doi.org/10.1044/2022_JSLHR-21-00245

Campbell, E. E., & Bergelson, E. (2022b). Making sense of sensory language: Acquisition of sensory knowledge by individuals with congenital sensory impairments. *Neuropsychologia*, *174*, 108320. https://doi.org/10.1016/j.neuropsychologia.2022.108320

Campbell, E. E., Casillas, R., & Bergelson, E. (submitted). *The Role of Vision in the Acquisition of Words: Vocabulary Development in Blind Toddlers*. https://doi.org/10.17605/OSF.IO/UW6ZM

Campbell, E. E., Zettersten, M., Lewis, M., & Bergelson, E. (2021, April 9). *Early Language in Blind, Deaf/Hard-of-Hearing, and Typically-Developing Infants*.

Campbell, J. (2003). Maternal Directives to Young Children who are Blind. *Journal of Visual Impairment & Blindness*, *97*(6), 355–365. https://doi.org/10.1177/0145482X0309700604

Carlyon, R. P., & Goehring, T. (2021). Cochlear Implant Research and Development in the Twenty-first Century: A Critical Update. *Journal of the Association for Research in Otolaryngology*, *22*(5), 481–508. https://doi.org/10.1007/s10162-021-00811-5

Carpenter, M., Nagell, K., Tomasello, M., Butterworth, G., & Moore, C. (1998). Social Cognition, Joint Attention, and Communicative Competence from 9 to 15 Months of Age. *Monographs of the Society for Research in Child Development*, *63*(4), i–174. https://doi.org/10.2307/1166214

Carr, K., & Kihm, J. (2022). MarkeTrak—Tracking the Pulse of the Hearing Aid Market. *Seminars in Hearing*, *43*(4), 277–288. https://doi.org/10.1055/s-0042-1758380

Caselli, N. K. (2015). *Language Deprivation and the American Sign Language Lexicon* [Ph.D., Tufts University]. https://www.proquest.com/docview/1725110495/abstract/D9C8F515B6534708PQ/1

Caselli, N. K., Lieberman, A. M., & Pyers, J. E. (2020). The ASL-CDI 2.0: An updated, normed adaptation of the MacArthur Bates Communicative Development Inventory for American Sign Language. *Behavior Research Methods*, *52*(5), 2071–2084. https://doi.org/10.3758/s13428-020-01376-6

Caselli, N. K., & Pyers, J. E. (2017). The Road to Language Learning Is Not Entirely Iconic: Iconicity, Neighborhood Density, and Frequency Facilitate Acquisition of Sign Language. *Psychological Science*, *28*(7), 979–987. https://doi.org/10.1177/0956797617700498

Caselli, N. K., & Pyers, J. E. (2020). Degree and not type of iconicity affects sign language vocabulary acquisition. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *46*(1), 127–139. https://doi.org/10.1037/xlm0000713

Caselli, N. K., Pyers, J., & Lieberman, A. M. (2021). Deaf Children of Hearing Parents Have Age-Level Vocabulary Growth When Exposed to American Sign Language by 6 Months of Age. *The Journal of Pediatrics*, *232*, 229–236. https://doi.org/10.1016/j.jpeds.2021.01.029

Caselli, N. K., Sehyr, Z. S., Cohen-Goldberg, A. M., & Emmorey, K. (2017). ASL-LEX: A lexical database of American Sign Language. *Behavior Research Methods*, *49*(2), 784–801. https://doi.org/10.3758/s13428-016-0742-0

Casillas, M., Brown, P., & Levinson, S. C. (2020). Early Language Experience in a Tseltal Mayan Village. *Child Development*, *91*(5), 1819–1835. https://doi.org/10.1111/cdev.13349

CDC. (2019, March 21). *Data and Statistics About Hearing Loss in Children | CDC*. Centers for Disease Control and Prevention. https://www.cdc.gov/ncbddd/hearingloss/data.html

Chernyak, P. (n.d.). *3 Ways to Teach Your Blind or Visually Impaired Child to Talk*. WikiHow. Retrieved April 21, 2023, from https://www.wikihow.life/Teach-Your-Blind-or-Visually-Impaired-Child-to-Talk

Chiesa, S., Galati, D., & Schmidt, S. (2015). Communicative interactions between visually impaired mothers and their sighted children: Analysis of gaze, facial expressions, voice and physical contacts. *Child: Care, Health and Development*, *41*(6), 1040–1046. https://doi.org/10.1111/cch.12274

Ching, T. Y. C., Dillon, H., Marnane, V., Hou, S., Day, J., Seeto, M., Crowe, K., Street, L., Thomson, J., Van Buynder, P., Zhang, V., Wong, A., Burns, L., Flynn, C., Cupples, L., Cowan, R. S. C., Leigh, G., Sjahalam-King, J., & Yeh, A. (2013). Outcomes of Early- and Late-identified Children at 3 Years of Age: Findings from a Prospective Population-based Study. *Ear and Hearing*, *34*(5), 535–552. https://doi.org/10.1097/AUD.0b013e3182857718

Christophe, A. (2016). *Bootstrapping the Syntactic Bootstrapper*.

Christophe, A., Mehler, J., & Sebastian-Galles, N. (2001). Perception of Prosodic Boundary Correlates by Newborn Infants. *Infancy*, *2*(3), 385–394. https://doi.org/10.1207/S15327078IN0203_6

Clark, M. D., Hauser, P. C., Miller, P., Kargin, T., Rathmann, C., Guldenoglu, B., Kubus, O., Spurgeon, E., & Israel, E. (2016). The Importance of Early Sign Language Acquisition for Deaf Readers. *Reading and Writing Quarterly*, *32*(2), 127–151. https://doi.org/10.1080/10573569.2013.878123

Colonnesi, C., Stams, G. J. J. M., Koster, I., & Noom, M. J. (2010). The relation between pointing and language development: A meta-analysis. *Developmental Review*, *30*(4), 352–366. https://doi.org/10.1016/j.dr.2010.10.001

Connell, L., & Lynott, D. (2012). Strength of perceptual experience predicts word processing performance better than concreteness or imageability. *Cognition*, *125*(3), 452–465. https://doi.org/10.1016/j.cognition.2012.07.010

Curtiss, S., Fromkin, V., Krashen, S., Rigler, D., & Rigler, M. (1974). The Linguistic Development of Genie. *Language*, *50*(3), 528. https://doi.org/10.2307/412222

Cutsforth, T. D. (1932). The Unreality of Words to the Blind. *Journal of Visual Impairment & Blindness*, *25*(5b), 86–89. https://doi.org/10.1177/0145482X3200400504

Dailey, S., & Bergelson, E. (2023). Talking to talkers: Infants' talk status, but not their gender, is related to language input. *Child Development*, *94*(2), 478–496. https://doi.org/10.1111/cdev.13872

Dale, N. J., Tadić, V., & Sonksen, P. (2014). Social communicative variation in 1-3-year-olds with severe visual impairment: Social communication in visually impaired 1-3-year-olds. *Child: Care, Health and Development*, *40*(2), 158–164. https://doi.org/10.1111/cch.12065

Davidson, K., Lillo-Martin, D., & Pichler, D. C. (2014). Spoken english language development among native signing children with cochlear implants. *Journal of Deaf Studies and Deaf Education*, *19*(2), 239–250. https://doi.org/10.1093/deafed/ent045

Davis, C. P., Joergensen, G. H., Boddy, P., Dowling, C., & Yee, E. (2020). Making It Harder to "See" Meaning: The More You See Something, the More Its Conceptual Representation Is Susceptible to Visual Interference. *Psychological Science*, *31*(5), 505–517. https://doi.org/10.1177/0956797620910748

de Diego-Lázaro, B., Restrepo, M. A., Sedey, A. L., & Yoshinaga-Itano, C. (2018). Predictors of Vocabulary Outcomes in Children Who Are Deaf or Hard of Hearing From Spanish-Speaking Families. *Language, Speech, and Hearing Services in Schools*, *50*(1), 1–13. https://doi.org/10.1044/2018_LSHSS-17-0148

De Villiers, J. (1985). Learning how to use verbs: Lexical coding and the influence of the input*. *Journal of Child Language*, *12*(3), 587–595. https://doi.org/10.1017/S0305000900006668

DeCasper, A. J., & Fifer, W. P. (1980). Of human bonding: Newborns prefer their mothers' voices. *Science (New York, N.Y.)*, *208*(4448), 1174–1176.

Delage, H., & Tuller, L. (2007). Language development and mild-to-moderate hearing loss: Does language normalize with age? *Journal of Speech, Language, and Hearing Research*, *50*(5), 1300–1313. https://doi.org/10.1044/1092-4388(2007/091)

Della Rosa, P. A., Catricalà, E., Vigliocco, G., & Cappa, S. F. (2010). Beyond the abstract-concrete dichotomy: Mode of acquisition, concreteness, imageability, familiarity, age of acquisition, context availability, and abstractness norms for a set of 417 Italian words. *Behavior Research Methods*, *42*(4), 1042–1048. https://doi.org/10.3758/BRM.42.4.1042

Demir, Ö. E., Rowe, M. L., Heller, G., Goldin-Meadow, S., & Levine, S. C. (2015). Vocabulary, syntax, and narrative development in typically developing children and children with early unilateral brain injury: Early parental talk about the "there-and-then" matters. *Developmental Psychology*, *51*(2), 161–175. https://doi.org/10.1037/a0038476

DeMott, R. M. (1972). Verbalism and affective meaning for blind, severely visually impaired, and normally sighted children. *New Outlook for the Blind*, *66*(1), 1–8, 25.

Dettman, S., Choo, D., Au, A., Luu, A., & Dowell, R. (2021). Speech Perception and Language Outcomes for Infants Receiving Cochlear Implants Before or After 9 Months of Age: Use of Category-Based Aggregation of Data in an Unselected Pediatric Cohort. *Journal of Speech, Language, and Hearing Research*, *64*(3), 1023–1039. https://doi.org/10.1044/2020_JSLHR-20-00228

Dirks, E., Stevens, A., Kok, S., Frijns, J., & Rieffe, C. (2020). Talk with me! Parental linguistic input to toddlers with moderate hearing loss. *Journal of Child Language*, *47*(1), 186–204. https://doi.org/10.1017/S0305000919000667

Dollaghan, C. (1985). Child Meets Word. *Journal of Speech, Language, and Hearing Research*, *28*(3), 449–454. https://doi.org/10.1044/jshr.2803.454

Donnellan, E., Bannard, C., McGillion, M. L., Slocombe, K. E., & Matthews, D. (2020). Infants' intentionally communicative vocalizations elicit responses from caregivers and are the best predictors of the transition to language: A longitudinal investigation of infants' vocalizations, gestures and word production. *Developmental Science*, *23*(1), e12843. https://doi.org/10.1111/desc.12843

Dote-Kwan, J. (1995). Impact of Mothers' Interactions on the Development of Their Young Visually Impaired Children. *Journal of Visual Impairment & Blindness*, *89*(1), 46–58. https://doi.org/10.1177/0145482X9508900109

Dunlea, A. (1989). *Vision and the emergence of meaning: Blind and sighted children's early language* (pp. xv, 196). Cambridge University Press. https://doi.org/10.1017/CBO9780511519802

Eimas, P. D., Siqueland, E. R., Jusczyk, P., & Vigorito, J. (1971). Speech perception in infants. *Science*, *171*, 303–306. https://doi.org/10.1126/science.171.3968.303

Eisenberg, L. S. (2007). Current state of knowledge: Speech recognition and production in children with hearing impairment. *Ear and Hearing*, *28*(6), 766–772. https://doi.org/10.1097/AUD.0b013e318157f01f

Emmorey, K., Nicodemus, Brenda, & O'Grady, Lucinda. (in press). *The language of perception inAmerican Sign Language*. PsyArXiv. https://doi.org/10.31234/osf.io/ed9bf

FamilyConnect. (n.d.). Understanding the Stages of Language Development for Babies Who Are Blind. *FamilyConnect*. Retrieved April 21, 2023, from https://familyconnect.org/browse-by-age/infants-and-toddlers/growth-and-development-iandt/language-development/

Fenson, L., Dale, P. S., Reznick, J. S., Bates, E., Thal, D. J., Pethick, S. J., Tomasello, M., Mervis, C. B., & Stiles, J. (1994). Variability in Early Communicative Development. *Monographs of the Society for Research in Child Development*, *59*(5), i. https://doi.org/10.2307/1166093

Ferjan Ramírez, N., Hippe, D. S., & Kuhl, P. K. (2021). Comparing Automatic and Manual Measures of Parent–Infant Conversational Turns: A Word of Caution. *Child Development*, *92*(2), 672–681. https://doi.org/10.1111/cdev.13495

Ferjan Ramírez, N., Lieberman, A. M., & Mayberry, R. I. (2013). The initial stages of first-language acquisition begun in adolescence: When late looks early. *Journal of Child Language*, *40*(2), 391–414. https://doi.org/10.1017/S0305000911000535

Fernald, A. (1989). Intonation and communicative intent in mothers' speech to infants: Is the melody the message? *Child Development*, *60*(6), 1497–1510.

Fisher, C., Gertner, Y., Scott, R. M., & Yuan, S. (2010). Syntactic bootstrapping. *WIREs Cognitive Science*, *1*(2), 143–149. https://doi.org/10.1002/wcs.17

Fisher, C., & Gleitman, L. R. (2002). Language acquisition. In *Steven's handbook of experimental psychology: Learning, motivation, and emotion, Vol. 3, 3rd ed* (pp. 445–496). John Wiley & Sons Inc.

Fisher, C., Jin, K., & Scott, R. (2020). The developmental origins of syntactic bootstrapping. *Topics in Cognitive Science*. https://scholar.google.com/citations?view_op=view_citation&hl=en&user=0GLXPcwAAAAJ&sortby=pubdate&citation_for_view=0GLXPcwAAAAJ:q3oQSFYPqjQC

Fourtassi, A., Scheinfeld, I., & Frank, M. (2019). The Development of Abstract Concepts in Children's Early Lexical Networks. *Proceedings of the Workshop on Cognitive Modeling and Computational Linguistics*, 129–133. https://doi.org/10.18653/v1/W19-2914

Fraiberg, S. (1975). The development of human attachments in infants blind from birth. *Merrill-Palmer Quarterly*, *21*, 315–334.

Fraiberg, S., & Fraiberg, L. (1977). *Insights from the blind: Comparative studies of blind and sighted infants*. Basic Books.

Frank, M. C., Braginsky, M., Yurovsky, D., & Marchman, V. A. (2017). Wordbank: An open repository for developmental vocabulary data. *Journal of Child Language*, *44*(3), 677–694. https://doi.org/10.1017/S0305000916000209

Frank, M. C., Braginsky, M., Yurovsky, D., & Marchman, V. A. (2021). *Variability and Consistency in Early Language Learning: The Wordbank Project*. The MIT Press.

Gallaudet Research Institute. (2014). *2013-2014 Annual Survey of Deaf and Hard of Hearing Children & Youth* (pp. 1–12). Office of Research Support and International Affairs, Gallaudet University. https://www.gallaudet.edu/documents/Research-Support-and-International-Affairs/Intl%20Affairs/Demographics/AS14_RegNat.pdf

Ganea, N., Hudry, K., Vernetti, A., Tucker, L., Charman, T., Johnson, M. H., & Senju, A. (2018). Development of adaptive communication skills in infants of blind parents. *Developmental Psychology*, *54*(12), 2265–2273. https://doi.org/10.1037/dev0000564

Ganea, P. A., & Saylor, M. M. (2013). Talking about the near and dear: Infants' comprehension of displaced speech. *Developmental Psychology*, *49*(7), 1299–1307. https://doi.org/10.1037/a0030086

Ganek, H., & Eriks-Brophy, A. (2018). Language ENvironment analysis (LENA) system investigation of day long recordings in children: A literature review. *Journal of Communication Disorders*, *72*, 77–85. https://doi.org/10.1016/j.jcomdis.2017.12.005

Garcia-Filion, P., & Borchert, M. (2013). Optic Nerve Hypoplasia Syndrome: A Review of the Epidemiology and Clinical Associations. *Current Treatment Options in Neurology*, *15*(1), 78–89. https://doi.org/10.1007/s11940-012-0209-2

Geers, A. E., Mitchell, C. M., Warner-Czyz, A., Wang, N. Y., & Eisenberg, L. S. (2017). Early sign language exposure and cochlear implantation benefits. *Pediatrics*, *140*(1). https://doi.org/10.1542/peds.2016-3489

Gergle, D., Kraut, R. E., & Fussell, S. R. (2004). Language Efficiency and Visual Technology: Minimizing Collaborative Effort with Visual Information. *Journal of Language and Social Psychology*, *23*(4), 491–517. https://doi.org/10.1177/0261927X04269589

Gilbert, C., & Awan, H. (2003). Blindness in children. *BMJ : British Medical Journal*, *327*(7418), 760–761.

Gilkerson, J., & Richards, J. A. (2008). *The LENA Natural Language Study*. LENA Foundation. https://www.lena.org/wp-content/uploads/2016/07/LTR-02-2_Natural_Language_Study.pdf

Gilkerson, J., Richards, J. A., Warren, S. F., Oller, D. K., Russo, R., & Vohr, B. (2018). Language Experience in the Second Year of Life and Language Outcomes in Late Childhood. *Pediatrics*, *142*(4), e20174276. https://doi.org/10.1542/peds.2017-4276

Gleitman, L. (1990). The Structural Sources of Verb Meanings. *Language Acquisition*, *1*(1), 3–55.

Glenberg, A. M., & Gallese, V. (2012). Action-based language: A theory of language acquisition, comprehension, and production. *Cortex*, *48*(7), 905–922. https://doi.org/10.1016/j.cortex.2011.04.010

Goldstein, M. H., & Schwade, J. A. (2008). Social feedback to infants' babbling facilitates rapid phonological learning. *Psychological Science*, *19*(5), 515–523. https://doi.org/10.1111/j.1467-9280.2008.02117.x

Golinkoff, R. M., & Hirsh-Pasek, K. (2006). Baby Wordsmith: From Associationist to Social Sophisticate. *Current Directions in Psychological Science*, *15*, 30–33. https://doi.org/10.1111/j.0963-7214.2006.00401.x

Golinkoff, R. M., Mervis, C. B., & Hirsh-Pasek, K. (1994). Early object labels: The case for a developmental lexical principles framework. *Journal of Child Language*, *21*(1), 125–155. https://doi.org/10.1017/S0305000900008692

González Cuenca, A., Lavigne Cervan, R., & Prieto Cuberos, M. (2020). Do Deaf Learners Reach the Necessary Linguistic Comprehension? *International Journal of Disability, Development and Education*, *67*(1), 92–106. https://doi.org/10.1080/1034912X.2019.1682527

Greenaway, R., & Dale, N. J. (2017). Congenital Visual Impairment. In *Research in Clinical Pragmatics*. https://www.researchgate.net/publication/312254295_Congenital_Visual_Impairment

Grice, H. P. (1975). Logic and Conversation. In *Syntax and semantics*. Academic press, Harcourt Brace Jovanovich.

Grigoroglou, M., Edu, U., & Papafragou, A. (2016). Are children flexible speakers? Effects of typicality and listener needs in children's event descriptions. *Cognitive Science*, 6.

Grimminger, A., Rohlfing, K. J., Lüke, C., Liszkowski, U., & Ritterfeld, U. (2020). Decontextualized talk in caregivers' input to 12-month-old children during structured interaction. *Journal of Child Language*, *47*(2), 418–434. https://doi.org/10.1017/S0305000919000710

Grumi, S., Cappagli, G., Aprile, G., Mascherpa, E., Gori, M., Provenzi, L., & Signorini, S. (2021). Togetherness, beyond the eyes: A systematic review on the interaction between visually impaired children and their parents. *Infant Behavior and Development*, *64*, 101590. https://doi.org/10.1016/j.infbeh.2021.101590

Gutman, A., Dautriche, I., Crabbé, B., & Christophe, A. (2015). Bootstrapping the Syntactic Bootstrapper: Probabilistic Labeling of Prosodic Phrases. *Language Acquisition*, *22*(3), 285–309. https://doi.org/10.1080/10489223.2014.971956

Gweon, H., Tenenbaum, J. B., & Schulz, L. E. (2010). Infants consider both the sample and the sampling process in inductive generalization. *PNAS Proceedings of the National Academy of Sciences of the United States of America*, *107*, 9066–9071. https://doi.org/10.1073/pnas.1003095107

Hadley, P. A., Rispoli, M., Holt, J. K., Papastratakos, T., Hsu, N., Kubalanza, M., & McKenna, M. M. (2017). Input Subject Diversity Enhances Early Grammatical Growth: Evidence from a Parent-Implemented Intervention. *Language Learning and Development: The Official Journal of the Society for Language Development*, *13*(1), 54–79. https://doi.org/10.1080/15475441.2016.1193020

Hall, M. L. (2020). The Input Matters: Assessing Cumulative Language Access in Deaf and Hard of Hearing Individuals and Populations. *Frontiers in Psychology*, *11*. https://www.frontiersin.org/articles/10.3389/fpsyg.2020.01407

Hall, M. L., & De, A. S. (2022). Estimating Early Language Input in Deaf and Hard of Hearing Children With the Language Access Profile Tool. *American Journal of Speech-Language Pathology*, *31*(5), 2132–2144. https://doi.org/10.1044/2022_AJSLP-21-00222

Hall, W. C., Levin, L. L., & Anderson, M. L. (2017). Language Deprivation Syndrome: A Possible Neurodevelopmental Disorder with Sociocultural Origins. *Social Psychiatry and Psychiatric Epidemiology*, *52*(6), 761–776. https://doi.org/10.1007/s00127-017-1351-7

Harley, R. K. (1963). *Verbalism Among Blind Children; An Investigation and Analysis. American Foundation for the Blind Research Series, Number 10*. https://eric.ed.gov/?id=ED025067

Harris, M., Jones, D., Brookes, S., & Grant, J. (1986). Relations between the non-verbal context of maternal speech and rate of language development. *British Journal of Developmental Psychology*, *4*(3), 261–268. https://doi.org/10.1111/j.2044-835X.1986.tb01017.x

Harrison, M., Roush, J., & Wallace, J. (2003). Trends in Age of Identification and Intervention in Infants with Hearing Loss. *Ear and Hearing*, *24*(1), 89–95. https://doi.org/10.1097/01.AUD.0000051749.40991.1F

Hassanzadeh, S. (2012). Outcomes of cochlear implantation in deaf children of deaf parents: Comparative study. *The Journal of Laryngology & Otology*, *126*(10), 989–994. https://doi.org/10.1017/S0022215112001909

Hawkins, R. D., Gweon, H., & Goodman, N. D. (2021). The Division of Labor in Communication: Speakers Help Listeners Account for Asymmetries in Visual Perspective. *Cognitive Science*, *45*(3), e12926. https://doi.org/10.1111/cogs.12926

Hazan, V., & Baker, R. (2011). Acoustic-phonetic characteristics of speech produced with communicative intent to counter adverse listening conditions. *The Journal of the Acoustical Society of America*, *130*(4), 2139–2152. https://doi.org/10.1121/1.3623753

Hemphill, L., & Tivnan, T. (2008). The Importance of Early Vocabulary for Literacy Achievement in High-Poverty Schools. *Journal of Education for Students Placed at Risk (JESPAR)*, *13*(4), 426–451. https://doi.org/10.1080/10824660802427710

Hilzensauer, M., & Krammer, K. (n.d.). *A multilingual dictionary for signed languages: "SPREADTHESIGN."* 8.

Hirsh-Pasek, K., Adamson, L. B., Bakeman, R., Owen, M. T., Golinkoff, R. M., Pace, A., Yust, P. K. S., & Suma, K. (2015). The Contribution of Early Communication Quality to Low-Income Children's Language Success. *Psychological Science*, *26*(7), 1071–1083. https://doi.org/10.1177/0956797615581493

Hirsh-Pasek, R. M. G., Kathy. (1999). Emergent Cues for Early Word Learning. In *The Emergence of Language*. Psychology Press.

Hoff, E. (2003). The specificity of environmental influence: Socioeconomic status affects early vocabulary development via maternal speech. *Child Development*, *74*(5), 1368–1378. https://doi.org/10.1111/1467-8624.00612

Hoff, E., & Naigles, L. (2002). How children use input to acquire a lexicon. *Child Development*, *73*(2), 418–433. https://doi.org/10.1111/1467-8624.00415

Holzinger, D., Fellinger, J., & Beitel, C. (2011). Early onset of family centred intervention predicts language outcomes in children with hearing loss. *International Journal of Pediatric Otorhinolaryngology*, *75*(2), 256–260. https://doi.org/10.1016/j.ijporl.2010.11.011

Hrastinski, I., & Wilbur, R. B. (2016). Academic Achievement of Deaf and Hard-of-Hearing Students in an ASL/English Bilingual Program. *Journal of Deaf Studies and Deaf Education*, *21*(2), 156–170. https://doi.org/10.1093/deafed/env072

Hsu, N., Hadley, P. A., & Rispoli, M. (2017). Diversity matters: Parent input predicts toddler verb production. *Journal of Child Language*, *44*(1), 63–86. https://doi.org/10.1017/S0305000915000690

Hudson, J. A. (2002). "Do You Know What We're Going to Do This Summer?": Mothers' Talk to Preschool Children About Future Events. *Journal of Cognition and Development*, *3*(1), 49–71. https://doi.org/10.1207/S15327647JCD0301_4

Hume, D. (1753). *Essays and Treatises on Several Subjects*. A. Millar.

Huttenlocher, J., Haight, W., Bryk, A., Seltzer, M., & Lyons, T. (1991). Early vocabulary growth: Relation to language input and gender. *Developmental Psychology*, *27*, 236–248. https://doi.org/10.1037/0012-1649.27.2.236

Huttenlocher, J., Vasilyeva, M., Cymerman, E., & Levine, S. (2002). Language input and child syntax. *Cognitive Psychology*, *45*(3), 337–374. https://doi.org/10.1016/s0010-0285(02)00500-5

Huttenlocher, J., Waterfall, H., Vasilyeva, M., Vevea, J., & Hedges, L. V. (2010). Sources of variability in children's language growth. *Cognitive Psychology*, *61*(4), 343–365. https://doi.org/10.1016/j.cogpsych.2010.08.002

Hym, C., Dumuids, M.-V., Anderson, D. I., Forma, V., Provasi, J., Brière-Dollat, C., Granjon, L., Gervain, J., Nazzi, T., & Barbu-Roth, M. (2023). Newborns modulate their crawling in response to their native language but not another language. *Developmental Science*, *26*(1), e13248. https://doi.org/10.1111/desc.13248

Iliev, R., & Axelrod, R. (2017). The Paradox of Abstraction: Precision Versus Concreteness. *Journal of Psycholinguistic Research*, *46*(3), 715–729. https://doi.org/10.1007/s10936-016-9459-6

Iverson, J. M., Tencer, H. L., Lany, J., & Goldin-Meadow, S. (2000). The relation between gesture and speech in congenitally blind and sighted language-learners. *Journal of Nonverbal Behavior*, *24*(2), 105–130. https://doi.org/10.1023/A:1006605912965

Jackson-Maldonado, D., Thal, D. J., Fenson, L., Marchman, V. A., Newton, T., Conboy, B., Bates, E., & Paul H. Brookes Publishing Company (Firm). (2003). *MacArthur Inventarios del Desarrollo de Habilidades Comunicativas: User's guide and technical manual*. P.H. Brookes.

James, G., Witten, D., Hastie, T., & Tibshirani, R. (2013). *An Introduction to Statistical Learning* (Vol. 103). Springer New York. https://doi.org/10.1007/978-1-4614-7138-7

Jara-Ettinger, J., & Rubio-Fernandez, P. (2021). The social basis of referential communication: Speakers construct physical reference based on listeners' expected visual search. *Psychological Review*, No Pagination Specified-No Pagination Specified. https://doi.org/10.1037/rev0000345

Jin, K., & Fisher, C. (2014). *Early evidence for syntactic bootstrapping: 15-month-olds use sentence structure in verb learning*.

Johnson, E. K., Seidl, A., & Tyler, M. D. (2014). The Edge Factor in Early Word Segmentation: Utterance-Level Prosody Enables Word Form Extraction by 6-Month-Olds. *PLOS ONE*, *9*(1), e83546. https://doi.org/10.1371/journal.pone.0083546

Jung, J., Reed, J., Wagner, L., Stephens, J., Warner-Czyz, A. D., Uhler, K., & Houston, D. (2020). Early Vocabulary Profiles of Young Deaf Children Who Use Cochlear Implants. *Journal of Speech, Language, and Hearing Research*, *63*(4), 1254–1269. https://doi.org/10.1044/2020_JSLHR-19-00315

Karchmer, M. A., & Mitchell, R. E. (2003). *Demographic and achievement characteristics of deaf and hard-of-hearing students. - PsycNET*. https://psycnet.apa.org/record/2003-00548-002

Kartushina, N., & Mayor, J. (2019). Word knowledge in six- to nine-month-old Norwegian infants? Not without additional frequency cues. *Royal Society Open Science*, *6*(9), 180711. https://doi.org/10.1098/rsos.180711

Kegl, R. V. S., Judy. (2018). Enhancing Communication Skills in Persons with Severe Language Deprivation: Lessons Learned from the Rise of a Signing Community in Nicaragua. In *Language Deprivation and Deaf Mental Health*. Routledge.

Kekelis, L. S., & Andersen, E. S. (1984). Family Communication Styles and Language Development. *Journal of Visual Impairment & Blindness*, *78*(2), 54–65. https://doi.org/10.1177/0145482X8407800202

Kennedy, C. R., McCann, D. C., Campbell, M. J., Law, C. M., Mullee, M., Petrou, S., Watkin, P., Worsfold, S., Yuen, H. M., & Stevenson, J. (2006). Language ability after early detection of permanent childhood hearing impairment. *New England Journal of Medicine*, *354*(20), 2131–2141. https://doi.org/10.1056/NEJMoa054915

Khatin-Zadeh, O., Eskandari, Z., Cervera-Torres, S., Ruiz Fernández, S., Farzi, R., & Marmolejo-Ramos, F. (2021). The strong versions of embodied cognition: Three challenges faced. *Psychology & Neuroscience*, *14*, 16–33. https://doi.org/10.1037/pne0000252

Kiese-Himmel, C., & Ohlwein, S. (2002). Vocabulary of young children with sensorineural deafness. *HNO*, *50*(1), 48–54. https://doi.org/10.1007/s106-002-8065-9

Kim, J. S., Aheimer, B., Manrara, V. M., & Bedny, M. (2020). *Shared understanding of color among congenitally blind and sighted adults*. PsyArXiv. https://doi.org/10.31234/osf.io/ufm3d

Kim, J. S., Elli, G. V., & Bedny, M. (2019). Knowledge of animal appearance among sighted and blind adults. *Proceedings of the National Academy of Sciences*, *116*(23), 11213–11222. https://doi.org/10.1073/pnas.1900952116

Kramer, J. A., Hill, K. T., & Cohen, L. B. (1975). Infants' Development of Object Permanence: A Refined Methodology and New Evidence for Piaget's Hypothesized Ordinality. *Child Development*, *46*(1), 149–155. https://doi.org/10.2307/1128843

Landau, B., & Gleitman, L. R. (1985). *Language and experience: Evidence from the blind child* (pp. xi, 250). Harvard University Press.

Lavechin, M., Bousbib, R., Bredin, H., Dupoux, E., & Cristia, A. (2021). *An open-source voice type classifier for child-centered daylong recordings* (arXiv:2005.12656). arXiv. https://doi.org/10.48550/arXiv.2005.12656

Lavi-Rotbain, O., & Arnon, I. (2022). Zipfian Distributions in Child-Directed Speech. *Open Mind*, 1–30. https://doi.org/10.1162/opmi_a_00070

Leat, S. J., Yadav, N. K., & Irving, E. L. (2009). Development of Visual Acuity and Contrast Sensitivity in Children. *Journal of Optometry*, *2*(1), 19–26. https://doi.org/10.3921/joptom.2009.19

Lehet, M., Arjmandi, M. K., Houston, D., & Dilley, L. (2021). Circumspection in using automated measures: Talker gender and addressee affect error rates for adult speech detection in the Language ENvironment Analysis (LENA) system. *Behavior Research Methods*, *53*(1), 113–138. https://doi.org/10.3758/s13428-020-01419-y

Lewis, M., Zettersten, M., & Lupyan, G. (2019). Distributional semantics as a source of visual knowledge. *Proceedings of the National Academy of Sciences*, *116*(39), 19237–19238. https://doi.org/10.1073/pnas.1910148116

Lisker, L., & Abramson, A. S. (1964). A Cross-Language Study of Voicing in Initial Stops: Acoustical Measurements. *WORD*, *20*(3), 384–422. https://doi.org/10.1080/00437956.1964.11659830

Locke, J. (1894). *An Essay Concerning Human Understanding*. Clarendon Press.

Loiotile, R., Lane, C., Omaki, A., & Bedny, M. (2020). Enhanced performance on a sentence comprehension task in congenitally blind adults. *Language, Cognition and Neuroscience*, *35*(8), 1010–1023. https://doi.org/10.1080/23273798.2019.1706753

Lorang, E., Venker, C. E., & Sterling, A. (2020). An investigation into maternal use of telegraphic input to children with Down syndrome. *Journal of Child Language*, *47*(1), 225–249. https://doi.org/10.1017/S0305000919000503

Lucariello, J., & Nelson, K. (1987). Remembering and planning talk between mothers and children. *Discourse Processes*, *10*(3), 219–235. https://doi.org/10.1080/01638538709544673

Lucca, K., & Wilbourn, M. P. (2018). Communicating to Learn: Infants' Pointing Gestures Result in Optimal Learning. *Child Development*, *89*(3), 941–960. https://doi.org/10.1111/cdev.12707

Lucca, K., & Wilbourn, M. P. (2019). The what and the how: Information-seeking pointing gestures facilitate learning labels and functions. *Journal of Experimental Child Psychology*, *178*, 417–436. https://doi.org/10.1016/j.jecp.2018.08.003

Luchkina, E., Xu, F., Sobel, D., & Morgan, J. (2020). *Sixteen-month-olds comprehend unanchored absent reference* [Preprint]. Open Science Framework. https://doi.org/10.31219/osf.io/5tc6d

Luckner, J. L., & Cooke, C. (2010). A summary of the vocabulary research with students who are deaf or hard of hearing. *American Annals of the Deaf*, *155*(1), 38–67. https://doi.org/10.1353/aad.0.0129

Lund, E. (2016). Vocabulary Knowledge of Children With Cochlear Implants: A Meta-Analysis. *The Journal of Deaf Studies and Deaf Education*, *21*(2), 107–121. https://doi.org/10.1093/deafed/env060

Luo, R., & Tamis-LeMonda, C. S. (2016). Mothers' Verbal and Nonverbal Strategies in Relation to Infants' Object-Directed Actions in Real Time and Across the First Three Years in Ethnically Diverse Families. *Infancy*, *21*(1), 65–89. https://doi.org/10.1111/infa.12099

Luu, T. M., Katz, S. L., Leeson, P., Thébaud, B., & Nuyt, A.-M. (2016). Preterm birth: Risk factor for early-onset chronic diseases. *CMAJ : Canadian Medical Association Journal*, *188*(10), 736–740. https://doi.org/10.1503/cmaj.150450

Lux, V., Non, A. L., Pexman, P. M., Stadler, W., Weber, L. A. E., & Krüger, M. (2021). A Developmental Framework for Embodiment Research: The Next Step Toward Integrating Concepts and Methods. *Frontiers in Systems Neuroscience*, *15*. https://www.frontiersin.org/articles/10.3389/fnsys.2021.672740

Lynott, D., Connell, L., Brysbaert, M., Brand, J., & Carney, J. (2020). The Lancaster Sensorimotor Norms: Multidimensional measures of perceptual and action strength for 40,000 English words. *Behavior Research Methods*, *52*(3), 1271–1291. https://doi.org/10.3758/s13428-019-01316-z

MacWhinney, B. (2014). *The CHILDES project: Tools for analyzing talk, Volume II: The database*. Psychology Press.

MacWhinney, B. (2019). *CHAT Manual*. https://doi.org/10.21415/3MHN-0Z89

Magimairaj, B., Nagaraj, N., Caballero, A., Munoz, K., & White, K. (2022). A Systematic Review of the Effects of LENA-based Feedback on Parent-Child Language Interactions in Families with Young Children. *Journal of Early Hearing Detection and Intervention*, *7*(3), 47–60. https://doi.org/10.26077/6c72-973b

Magnuson, M. (2000). Infants with Congenital Deafness: On the Importance of Early Sign Language Acquisition. *American Annals of the Deaf*, *145*(1), 6–14. https://doi.org/10.1353/aad.2012.0256

Mahon, B. Z., & Caramazza, A. (2008). A critical look at the embodied cognition hypothesis and a new proposal for grounding conceptual content. *Journal of Physiology-Paris*, *102*(1–3), 59–70. https://doi.org/10.1016/j.jphysparis.2008.03.004

MALKOWICZ, D. E., MYERS, G., & LEISMAN, G. (2006). Rehabilitation of Cortical Visual Impairment in Children. *International Journal of Neuroscience*, *116*(9), 1015–1033. https://doi.org/10.1080/00207450600553505

Manning, B. L., Roberts, M. Y., Estabrook, R., Petitclerc, A., Burns, J. L., Briggs-Gowan, M., Wakschlag, L. S., & Norton, E. S. (2019). Relations between toddler expressive language and temper tantrums in a community sample. *Journal of Applied Developmental Psychology*, *65*, 101070. https://doi.org/10.1016/j.appdev.2019.101070

Marchman, M. C. F., Mika Braginsky, Daniel Yurovsky, and Virginia A. (2021). *Variability and Consistency in Early Language Learning*. MIT Press. https://langcog.github.io/wordbank-book/

Marnane, V., & Ching, T. Y. C. (2015). Hearing aid and cochlear implant use in children with hearing loss at three years of age: Predictors of use and predictors of changes in use. *International Journal of Audiology*, *54*(8), 544–551. https://doi.org/10.3109/14992027.2015.1017660

Martinez-Alvarez, A., Benavides-Varela, S., Lapillonne, A., & Gervain, J. (2023). Newborns discriminate utterance-level prosodic contours. *Developmental Science*, *26*(2), e13304. https://doi.org/10.1111/desc.13304

Mayberry, R. I. (1993). First-Language Acquisition After Childhood Differs From Second-Language Acquisition. *Journal of Speech, Language, and Hearing Research*, *36*(6), 1258–1270. https://doi.org/10.1044/jshr.3606.1258

Mayberry, R. I., Chen, J.-K., Witcher, P., & Klein, D. (2011). Age of acquisition effects on the functional organization of language in the adult brain. *Brain and Language*, *119*(1), 16–29. https://doi.org/10.1016/j.bandl.2011.05.007

Mayberry, R. I., & Squires, B. (2006). *Sign Language: Acquisition*. *11*, 7.

McAlpine, L. M., & Moore, C. L. (1995). The Development of Social Understanding in Children with Visual Impairments. *Journal of Visual Impairment & Blindness*, *89*(4), 349–358. https://doi.org/10.1177/0145482X9508900408

McConachie, H. (1990). Early language development and severe visual impairment. *Child: Care, Health and Development*, *16*(1), 55–61. https://doi.org/10.1111/j.1365-2214.1990.tb00638.x

Mcconachie, H. R., & Moore, V. (1994). Early Expressive Language of Severely Visually Impaired Children. *Developmental Medicine and Child Neurology*, *36*, 230–240.

McHugh, M. L. (2013). The Chi-square test of independence. *Biochemia Medica*, *23*(2), 143–149. https://doi.org/10.11613/BM.2013.018

McRae, K. A. (2002). *Attachment in blind infants: A systematic investigation using Ainsworth's Strange Situation.* [University of Toronto]. https://library-archives.canada.ca/eng/services/services-libraries/theses/Pages/item.aspx?idNumber=55682060

Meltzoff, A. N., & Brooks, R. (2009). Social cognition and language: The role of gaze following in early word learning. In *Infant pathways to language: Methods, models, and research disorders* (pp. 169–194). Psychology Press.

Meylan, S. C., & Bergelson, E. (2022). Learning Through Processing: Toward an Integrated Approach to Early Word Learning. *Annual Review of Linguistics*, *8*(1), 77–99. https://doi.org/10.1146/annurev-linguistics-031220-011146

Minervino, R. A., Martín, A., Tavernini, L. M., & Trench, M. (2018). The Understanding of Visual Metaphors by the Congenitally Blind. *Frontiers in Psychology*, *9*. https://doi.org/10.3389/fpsyg.2018.01242

Mitchell, R. E., & Karchmer, M. A. (2004). Chasing the Mythical Ten Percent: Parental Hearing Status of Deaf and Hard of Hearing Students in the United States. *Sign Language Studies*, *4*(2), 138–163.

Mitchell, R. E., & Karchmer, M. A. (2005). Parental Hearing Status and Signing among Deaf and Hard of Hearing Students. *Sign Language Studies*, *5*(2), 231–244. https://doi.org/10.1353/sls.2005.0004

Moeller, M. P., Tomblin, J. B., Yoshinaga-Itano, C., Connor, C. M. D., & Jerger, S. (2007). Current state of knowledge: Language and literacy of children with hearing impairment. In *Ear and Hearing* (Vol. 28). https://doi.org/10.1097/AUD.0b013e318157f07f

Mohan, K. M., & Dobson, V. (2000). When Does Measured Visual Field Extent Become Adult-like? It Depends. *Vision Science and Its Applications (2000), Paper FA3*, FA3. https://doi.org/10.1364/VSIA.2000.FA3

Montag, J. L., Jones, M. N., & Smith, L. B. (2018). Quantity and Diversity: Simulating Early Word Learning Environments. *Cognitive Science*, *42 Suppl 2*(Suppl 2), 375–412. https://doi.org/10.1111/cogs.12592

Moore, C., Dailey, S., Garrison, H., Amatuni, A., & Bergelson, E. (2019). Point, Walk, Talk: Links Between Three Early Milestones, from Observation and Parental Report. *Developmental Psychology*, *55*(8), 1579–1593. https://doi.org/10.1037/dev0000738

Moore, V., & McConachie, H. (1994). Communication between blind and severely visually impaired children and their parents. *British Journal of Developmental Psychology*, *12*(4), 491–502. https://doi.org/10.1111/j.2044-835X.1994.tb00650.x

Morgan, H., Novogrodsky, R., & Sandler, W. (2019, September 28). *Phonological complexity and frequency in the lexicon: A quantitative cross-linguistic study*. Theoretical Issues in Sign Language Research Conference, University of Hamburg. https://fiona.uni-hamburg.de/82b0d2a4/conferencehandbook.pdf

Mulford, R. (1988). First words of the blind child. In *The emergent lexicon: The child's development of a linguistic vocabulary* (pp. 293–338). Academic Press, Inc.

Muraki, E. J., Siddiqui, I. A., & Pexman, P. M. (2022). Quantifying children's sensorimotor experience: Child body-object interaction ratings for 3359 English words. *Behavior Research Methods*, *54*(6), 2864–2877. https://doi.org/10.3758/s13428-022-01798-4

Nagayoshi, M., Hirose, T., Toju, K., Suzuki, S., Okamitsu, M., Teramoto, T., Omori, T., Kawamura, A., & Takeo, N. (2017). Related visual impairment to mother-infant interaction and development in infants with bilateral retinoblastoma. *European Journal of Oncology Nursing: The Official Journal of European Oncology Nursing Society*, *28*, 28–34. https://doi.org/10.1016/j.ejon.2017.02.002

Naigles, L. (1990). Children use syntax to learn verb meanings*. *Journal of Child Language*, *17*(2), 357–374. https://doi.org/10.1017/S0305000900013817

Naigles, L., & Hoff-Ginsberg, E. (1998). Why are some verbs learned before other verbs? Effects of input frequency and structure on children's early verb use. *Journal of Child Language*, *25*(1), 95–120. https://doi.org/10.1017/S0305000997003358

Nakisa, M. J., Summerfield, A. Q., Nakisa, R. C., McCormick, B., Archbold, S., Gibbin, K. P., & O'Donoghue, G. M. (2001). Functionally equivalent ages and hearing levels of children with cochlear implants measured with pre-recorded stimuli. *British Journal of Audiology*, *35*(3), 183–198. https://doi.org/10.1080/00305364.2001.11745236

Nelson, K. (1973). Structure and Strategy in Learning to Talk. *Monographs of the Society for Research in Child Development*, *38*(1/2), 1–135. https://doi.org/10.2307/1165788

Newman, R. S., Rowe, M. L., & Bernstein Ratner, N. (2016). Input and uptake at 7 months predicts toddler vocabulary: The role of child-directed speech and infant processing skills in language development. *Journal of Child Language*, *43*(5), 1158–1173. https://doi.org/10.1017/S0305000915000446

Nicholas, J. G., & Geers, A. E. (2007). Will they catch up? The role of age at cochlear implantation in the spoken language development of children with severe to profound hearing loss. *Journal of Speech, Language, and Hearing Research : JSLHR*. https://doi.org/10.1044/1092-4388(2007/073)

Niparko, J. K., Tobey, E. A., Thal, D. J., Eisenberg, L. S., Wang, N. Y., Quittner, A. L., & Fink, N. E. (2010). Spoken language development in children following cochlear implantation. *JAMA - Journal of the American Medical Association*, *303*(15), 1498–1506. https://doi.org/10.1001/jama.2010.451

Norgate, S. H. (1997). Research methods for studying the language of blind children. In *Encyclopedia of Language and Education* (pp. 165–173). Kluwer Academic.

Norris, M. (1957). *Blindness in children*. University of Chicago Press.

Osina, M. A., Saylor, M. M., & Ganea, P. A. (2013). When familiar is not better: 12-month-old infants respond to talk about absent objects. *Developmental Psychology*, *49*, 138–145. https://doi.org/10.1037/a0027903

Ostarek, M., Paridon, J. van, & Montero-Melis, G. (2019). Sighted people's language is not helpful for blind individuals' acquisition of typical animal colors. *Proceedings of the National Academy of Sciences*, *116*(44), 21972–21973. https://doi.org/10.1073/pnas.1912302116

Pancsofar, N., & Vernon-Feagans, L. (2006). Mother and father language input to young children: Contributions to later language development. *Journal of Applied Developmental Psychology*, *27*(6), 571–587. https://doi.org/10.1016/j.appdev.2006.08.003

Pasta, A., Szatmari, T.-I., Christensen, J. H., Jensen, K. J., Pontoppidan, N. H., Sun, K., & Larsen, J. E. (2021). Clustering Users Based on Hearing Aid Use: An Exploratory Analysis of Real-World Data. *Frontiers in Digital Health*, *3*, 725130. https://doi.org/10.3389/fdgth.2021.725130

Pénicaud, S., Klein, D., Zatorre, R. J., Chen, J.-K., Witcher, P., Hyde, K., & Mayberry, R. I. (2013). Structural brain changes linked to delayed first language acquisition in congenitally deaf individuals. *NeuroImage*, *66*, 42–49. https://doi.org/10.1016/j.neuroimage.2012.09.076

Pérez-Pereira, M. (1994). Imitations, repetitions, routines, and the child's analysis of language: Insights from the blind. *Journal of Child Language*, *21*(2), 317–337. https://doi.org/10.1017/S0305000900009296

Perez-Pereira, M., & Conti-Ramsden, G. (1999). *Language Development and Social Interaction in Blind Children*. Psychology Press. https://doi.org/10.4324/9780203776087

Pérez-Pereira, M., & Conti-Ramsden, G. (2001). The use of Directives in Verbal Interactions between Blind Children and their Mothers. *Journal of Visual Impairment & Blindness*, *95*(3), 133–149. https://doi.org/10.1177/0145482x0109500302

Perlman, M., Little, H., Thompson, B., & Thompson, R. L. (2018). Iconicity in Signed and Spoken Vocabulary: A Comparison Between American Sign Language, British Sign Language, English, and Spanish. *Frontiers in Psychology*, *9*. https://doi.org/10.3389/fpsyg.2018.01433

Perniss, P., & Vigliocco, G. (2014). The bridge of iconicity: From a world of experience to the experience of language. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *369*(1651), 20130300. https://doi.org/10.1098/rstb.2013.0300

Perry, L. K., Perlman, M., & Lupyan, G. (2015). Iconicity in English and Spanish and Its Relation to Lexical Category and Age of Acquisition. *PLOS ONE*, *10*(9), e0137147. https://doi.org/10.1371/journal.pone.0137147

Petitto, L. A., & Marentette, P. (1991). Babbling in the Manual Mode: Evidence for the Ontogeny of Language. *Science (New York, N.Y.)*, *251*, 1493–1496. https://doi.org/10.1126/science.2006424

Pexman, P. M. (2019). The role of embodiment in conceptual development. *Language, Cognition and Neuroscience*, *34*(10), 1274–1283. https://doi.org/10.1080/23273798.2017.1303522

Piaget, J. (1952). *The origins of intelligence in children.* (M. Cook, Trans.). W W Norton & Co. https://doi.org/10.1037/11494-000

Piattelli-Palmarini, M. (1980). *Language and Learning: The Debate Between Jean Piaget and Noam Chomsky* (M. Piattelli-Palmarini, Ed.). Harvard University Press.

Pierrat, V., Marchand-Martin, L., Arnaud, C., Kaminski, M., Resche-Rigon, M., Lebeaux, C., Bodeau-Livinec, F., Morgan, A. S., Goffinet, F., Marret, S., Ancel, P.-Y., & Group, and the E.-2 writing. (2017). Neurodevelopmental outcome at 2 years for preterm children born at 22 to 34 weeks' gestation in France in 2011: EPIPAGE-2 cohort study. *BMJ*, *358*. https://doi.org/10.1136/bmj.j3448

Pisani, S., Gautheron, L., & Cristia, A. (2021). *Long-form recordings: From A to Z*. https://bookdown.org/alecristia/exelang-book/

Pisoni, D. B., Kronenberger, W. G., Harris, M. S., & Moberly, A. C. (2018). Three challenges for future research on cochlear implants. *World Journal of Otorhinolaryngology - Head and Neck Surgery*. https://doi.org/10.1016/j.wjorl.2017.12.010

Ponari, M., Norbury, C. F., & Vigliocco, G. (2017). Acquisition of abstract concepts is influenced by emotional valence. *Developmental Science*, *21*(2). https://doi.org/DOI: 10.1111/desc.12549

Ponari, M., Norbury, C. F., & Vigliocco, G. (2020). The role of emotional valence in learning novel abstract concepts—PubMed. *Developmental Psychology*, *56*(10), 1855–1865. https://doi.org/doi: 10.1037/dev0001091

Preisler, G. M. (1991). Early patterns of interaction between blind infants and their sighted mothers. *Child: Care, Health and Development*, *17*(2), 65–90. https://doi.org/10.1111/j.1365-2214.1991.tb00680.x

Pruden, S. M., Hirsh-Pasek, K., Golinkoff, R. M., & Hennon, E. A. (2006). The Birth of Words: Ten-Month-Olds Learn Words Through Perceptual Salience. *Child Development*, *77*(2), 266–280. https://doi.org/10.1111/j.1467-8624.2006.00869.x

Qi, S., & Mitchell, R. E. (2012). Large-Scale Academic Achievement Testing of Deaf and Hard-of-Hearing Students: Past, Present, and Future. *Journal of Deaf Studies and Deaf Education*, *17*(1), 1–18. https://doi.org/10.1093/deafed/enr028

Reed, H. B., & Dick, R. D. (1968). The learning and generalization of abstract and concrete concepts. *Journal of Verbal Learning and Verbal Behavior*, *7*(2), 486–490. https://doi.org/10.1016/S0022-5371(68)80037-4

Richards, B. (1987). Type/Token Ratios: What do they really tell us? *Journal of Child Language*, *14*(2), 201. https://doi.org/doi:10.1017/s0305000900012885

Robinshaw, H. M. (1995). Early intervention for hearing impairment: Differences in the timing of communicative and linguistic development. *British Journal of Audiology*, *29*(6), 315–334. https://doi.org/10.3109/03005369509076750

Röder, B., Demuth, L., Streb, J., & Rösler, F. (2003). Semantic and morpho-syntactic priming in auditory word recognition in congenitally blind adults. *Language and Cognitive Processes*, *18*(1), 1–20. https://doi.org/10.1080/01690960143000407

Röder, B., Rösler, F., & Neville, H. J. (2000). Event-related potentials during auditory language processing in congenitally blind and sighted people. *Neuropsychologia*, *38*(11), 1482–1502. https://doi.org/10.1016/S0028-3932(00)00057-9

Rodriguez, Y. S., & Allen, T. E. (2020). Exploring Hispanic parents' beliefs and attitudes about deaf education. *Journal of Latinos and Education*, *19*(1), 45–55. https://doi.org/10.1080/15348431.2018.1463848

Rogers, S. J., & Puchalski, C. B. (1984). Social Characteristics of Visually Impaired Infants' Play. *Topics in Early Childhood Special Education*, *3*(4), 52–56. https://doi.org/10.1177/027112148400300409

Rogers, S. J., & Puchalski, C. B. (1988). Development of Object Permanence in Visually Impaired Infants. *Journal of Visual Impairment & Blindness*, *82*(4), 137–142. https://doi.org/10.1177/0145482X8808200407

Romeo, R. R., Leonard, J. A., Robinson, S. T., West, M. R., Mackey, A. P., Rowe, M. L., & Gabrieli, J. D. E. (2018). Beyond the 30-Million-Word Gap: Children's Conversational Exposure Is Associated With Language-Related Brain Function. *Psychological Science*, *29*(5), 700–710. https://doi.org/10.1177/0956797617742725

Roseberry, S., Hirsh-Pasek, K., & Golinkoff, R. M. (2014). Skype me! Socially contingent interactions help toddlers learn language. *Child Development*, *85*(3), 956–970. https://doi.org/10.1111/cdev.12166

Rowe, M. L. (2008). Child-directed speech: Relation to socioeconomic status, knowledge of child development and child vocabulary skill*. *Journal of Child Language*, *35*(1), 185–205. https://doi.org/10.1017/S0305000907008343

Rowe, M. L. (2012). A longitudinal investigation of the role of quantity and quality of child-directed speech in vocabulary development. *Child Development*, *83*(5), 1762–1774. https://doi.org/10.1111/j.1467-8624.2012.01805.x

Rowe, M. L. (2013). Decontextualized Language Input and Preschoolers' Vocabulary Development. *Seminars in Speech and Language*, *34*(4), 260–266. https://doi.org/10.1055/s-0033-1353444

Rowe, M. L., & Snow, C. E. (2020). Analyzing input quality along three dimensions: Interactive, linguistic, and conceptual. *Journal of Child Language*, *47*(1), 5–21. https://doi.org/10.1017/S0305000919000655

Rowland, C. (1984). Preverbal Communication of Blind Infants and Their Mothers. *Journal of Visual Impairment & Blindness*, *78*(7), 297–302. https://doi.org/10.1177/0145482X8407800701

Rubio-Fernandez, P. (2019). Overinformative Speakers Are Cooperative: Revisiting the Gricean Maxim of Quantity. *Cognitive Science*, *43*(11), e12797. https://doi.org/10.1111/cogs.12797

Sanchez, A., Meylan, S. C., Braginsky, M., MacDonald, K. E., Yurovsky, D., & Frank, M. C. (2019). childes-db: A flexible and reproducible interface to the child language data exchange system. *Behavior Research Methods*, *51*(4), 1928–1941. https://doi.org/10.3758/s13428-018-1176-7

Sandbank, M., & Yoder, P. (2016). The Association Between Parental Mean Length of Utterance and Language Outcomes in Children With Disabilities: A Correlational Meta-Analysis. *American Journal of Speech-Language Pathology*, *25*(2), 240–251. https://doi.org/10.1044/2015_AJSLP-15-0003

Saysani, A., Corballis, M. C., & Corballis, P. M. (2021). Seeing colour through language: Colour knowledge in the blind and sighted. *Visual Cognition*, *29*(1), 63–71.

Schick, B., de Villiers, P., de Villiers, J., & Hoffmeister, R. (2007). Language and theory of mind: A study of deaf children. *Child Development*, *78*(2), 376–396. https://doi.org/10.1111/j.1467-8624.2007.01004.x

Schmidt, H. J., & Beauchamp, G. K. (1992). Human Olfaction in Infancy and Early Childhood. In M. J. Serby & K. L. Chobor (Eds.), *Science of Olfaction* (pp. 378–395). Springer New York. https://doi.org/10.1007/978-1-4612-2836-3_13

Schwanenflugel, P. J., & Shoben, E. J. (1983). Differential context effects in the comprehension of abstract and concrete verbal materials. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *9*, 82–102. https://doi.org/10.1037/0278-7393.9.1.82

Sehyr, Z. S., Caselli, N. K., Cohen-Goldberg, A. M., & Emmorey, K. (2021). The ASL-LEX 2.0 Project: A Database of Lexical and Phonological Properties for 2,723 Signs in American Sign Language. *The Journal of Deaf Studies and Deaf Education*, *26*(2), 263–277. https://doi.org/10.1093/deafed/enaa038

Seiberth, V., & Linderkamp, O. (2000). Risk Factors in Retinopathy of Prematurity: A Multivariate Statistical Analysis. *Ophthalmologica*, *214*(2), 131–135. https://doi.org/10.1159/000027482

Senju, A., Tucker, L., Pasco, G., Hudry, K., Elsabbagh, M., Charman, T., & Johnson, M. H. (2013). The importance of the eyes: Communication skills in infants of blind parents. *Proceedings. Biological Sciences*, *280*(1760), 20130436. https://doi.org/10.1098/rspb.2013.0436

Shneidman, L. A., Arroyo, M. E., Levine, S. C., & Goldin-Meadow, S. (2013). What counts as effective input for word learning? *Journal of Child Language*, *40*(3), 672–686. https://doi.org/10.1017/S0305000912000141

Skotara, N., Salden, U., Kügow, M., Hänel-Faulhaber, B., & Röder, B. (2012). The influence of language deprivation in early childhood on L2 processing: An ERP comparison of deaf native signers and deaf signers with a delayed language acquisition. *BMC Neuroscience*, *13*(1), 44. https://doi.org/10.1186/1471-2202-13-44

Slone, L. K., Smith, L. B., & Yu, C. (2019). Self-generated variability in object images predicts vocabulary growth. *Developmental Science*, *22*(6), e12816. https://doi.org/10.1111/desc.12816

Smith, L. (2000). Learning how to learn words: An associative crane. In *R. Golinkoff & K. Hirsh-Pasek (eds.), Becoming a word learner: A debate on lexical acquisition*. Oxford University Press.

Smith, L., Yu, C., & Pereira, A. F. (2011). Not your mother's view: The dynamics of toddler visual experience. *Developmental Science*, *14*(1), 9–17. https://doi.org/10.1111/j.1467-7687.2009.00947.x

Snow, C. E. (1972). Mothers' Speech to Children Learning Language. *Child Development*, *43*(2), 549–565. https://doi.org/10.2307/1127555

Soderstrom, M., Casillas, M., Bergelson, E., Rosemberg, C., Alam, F., Warlaumont, A. S., & Bunce, J. (2021). Developing a Cross-Cultural Annotation System and MetaCorpus for Studying Infants' Real World Language Experience. *Collabra: Psychology*, *7*(1), 23445. https://doi.org/10.1525/collabra.23445

Spencer, P. E. (1993). The expressive communication of hearing mothers and deaf infants. *American Annals of the Deaf*, *138*(3), 275–283. https://doi.org/10.1353/aad.2012.0414

Stæhr, L. S. (2008). Vocabulary size and the skills of listening, reading and writing. *The Language Learning Journal*, *36*(2), 139–152. https://doi.org/10.1080/09571730802389975

Steinberg, A., Bain, L., Li, Y., Delgado, G., & Ruperto, V. (2003). Decisions Hispanic families make after the identification of deafness. *Journal of Deaf Studies and Deaf Education*, *8*(3), 291–314. https://doi.org/10.1093/deafed/eng016

Stevenson, M. B., Leavitt, L. A., Roach, M. A., Chapman, R. S., & Miller, J. F. (1986). Mothers' speech to their 1-year-old infants in home and laboratory settings. *Journal of Psycholinguistic Research*, *15*(5), 451–461. https://doi.org/10.1007/BF01067725

Stika, C. J., Eisenberg, L. S., Johnson, K. C., Henning, S. C., Colson, B. G., Ganguly, D. H., & DesJardin, J. L. (2015). Developmental Outcomes of Early-Identified Children who are Hard of Hearing at 12 to 18 Months of Age. *Early Human Development*, *91*(1), 47–55. https://doi.org/10.1016/j.earlhumdev.2014.11.005

Striem-Amit, E., Wang, X., Bi, Y., & Caramazza, A. (2018). Neural representation of visual concepts in people born blind. *Nature Communications*, *9*(1), 5250. https://doi.org/10.1038/s41467-018-07574-3

Suarez-Rivera, C., Linn, E., & Tamis-LeMonda, C. S. (2022). From Play to Language: Infants' Actions on Objects Cascade to Word Learning. *Language Learning*, *72*(4), 1092–1127. https://doi.org/10.1111/lang.12512

Subbiah, K., Mason, C., Gaffney, M., & Grosse, S. (2018). Progress in Documented Early Identification and Intervention for Deaf and Hard of Hearing Infants – CDC's Hearing Screening and Follow-up Survey, United States, 2006–2016. *Journal of Early Hearing Detection and Intervention*, *3*(2), 1–7. https://doi.org/10.26077/6sj1-mw42

Svirsky, M. A., Teoh, S. W., & Neuburger, H. (2004). Development of language and speech perception in congenitally, profoundly deaf children as a function of age at cochlear implantation. *Audiology and Neuro-Otology*, *9*(4), 224–233. https://doi.org/10.1159/000078392

Takahashi, N., Isaka, Y., Yamamoto, T., & Nakamura, T. (2017). Vocabulary and Grammar Differences Between Deaf and Hearing Students. *The Journal of Deaf Studies and Deaf Education*, *22*(1), 88–104. https://doi.org/10.1093/deafed/enw055

Tamis-LeMonda, C. S., Kuchirko, Y., & Tafuro, L. (2013). From Action to Interaction: Infant Object Exploration and Mothers' Contingent Responsiveness. *IEEE Transactions on Autonomous Mental Development*, *5*(3), 202–209. https://doi.org/10.1109/TAMD.2013.2269905

Templin, M. C. (1957). *Certain language skills in children; their development and interrelationships* (pp. xviii, 183). University of Minnesota Press.

Teufel, C., Clayton, N. S., & Russell, J. (2013). Two-Year-Old Children's Understanding of Visual Perception and Knowledge Formation in Others. *Journal of Cognition and Development*, *14*(2), 203–228. https://doi.org/10.1080/15248372.2012.664591

Thal, D., Desjardin, J., & Eisenberg, L. S. (2007). Validity of the MacArthur–Bates Communicative Development Inventories for Measuring Language Abilities in

Children With Cochlear Implants. *Article in American Journal of Speech-Language Pathology*, 54–64. https://doi.org/10.1044/1058-0360(2007/007)

Thiessen, E. D., Hill, E. A., & Saffran, J. R. (2005). Infant-Directed Speech Facilitates Word Segmentation. *Infancy: The Official Journal of the International Society on Infant Studies*, *7*(1), 53–71. https://doi.org/10.1207/s15327078in0701_5

Thill, S., & Twomey, K. E. (2016). What's on the Inside Counts: A Grounded Account of Concept Acquisition and Development. *Frontiers in Psychology*, *7*. https://www.frontiersin.org/articles/10.3389/fpsyg.2016.00402

Tincoff, R., & Jusczyk, P. W. (1999). Some beginnings of word comprehension in 6-month-olds. *Psychological Science*, *10*(2), 172–175. https://doi.org/10.1111/1467-9280.00127

Tincoff, R., & Jusczyk, P. W. (2012). Six-month-olds comprehend words that refer to parts of the body. *Infancy*, *17*(4), 432–444. https://doi.org/10.1111/j.1532-7078.2011.00084.x

Tomasello, M. (2001). First steps toward a usage-based theory of language acquisition. *Cognitive Linguistics*, *11*(1–2). https://doi.org/10.1515/cogl.2001.012

Tomasello, M. (2003). The key is social cognition. *Language in Mind: Advances in the Study of Language and Thought*, 47–57.

Tomasello, M., & Farrar, M. J. (1986). Joint Attention and Early Language. *Child Development*, *57*(6), 1454. https://doi.org/10.2307/1130423

Tröster, H., & Brambring, M. (1992). Early social-emotional development in blind infants. *Child: Care, Health and Development*, *18*(4), 207–227. https://doi.org/10.1111/j.1365-2214.1992.tb00355.x

Trumpp, N. M., Kliese, D., Hoenig, K., Haarmeier, T., & Kiefer, M. (2013). Losing the sound of concepts: Damage to auditory association cortex impairs the processing of sound-related concepts. *Cortex*, *49*(2), 474–486. https://doi.org/10.1016/j.cortex.2012.02.002

Uccelli, P., Demir-Lira, Ö. E., Rowe, M. L., Levine, S., & Goldin-Meadow, S. (2019). Children's Early Decontextualized Talk Predicts Academic Language Proficiency in Midadolescence. *Child Development*, *90*(5), 1650–1663. https://doi.org/10.1111/cdev.13034

Unger, L., Vales, C., & Fisher, A. V. (2020). The Role of Co-Occurrence Statistics in Developing Semantic Knowledge. *Cognitive Science*, *44*(9), e12894. https://doi.org/10.1111/cogs.12894

Urwin, C. (1983). *Dialogue and cognitive functioning in the early language development of three blind children: Normal and deficient*. 142–161.

Urwin, C. (1984). Language for absent things: Learning from visually handicapped children. *Topics in Language Disorders*, *4*(4), 24.

van Paridon, J., Liu, Q., & Lupyan, G. (2021). *How do blind people know that blue is cold? Distributional semantics encode color-adjective associations.* PsyArXiv. https://doi.org/10.31234/osf.io/vyxpq

VanDam, M., Ambrose, S. E., & Moeller, M. P. (2012). Quantity of Parental Language in the Home Environments of Hard-of-Hearing 2-Year-Olds. *The Journal of Deaf Studies and Deaf Education*, *17*(4), 402–420. https://doi.org/10.1093/deafed/ens025

Verhaert, N., Willems, M., Van Kerschaver, E., & Desloovere, C. (2008). Impact of early hearing screening and treatment on language development and education level: Evaluation of 6 years of universal newborn hearing screening (ALGO®) in Flanders, Belgium. *International Journal of Pediatric Otorhinolaryngology*, *72*(5), 599–608. https://doi.org/10.1016/j.ijporl.2008.01.012

Vigliocco, G., Meteyard, L., Andrews, M., & Kousta, S. (2009). *Toward a theory of semantic representation*. *1*(2), 219–247. https://doi.org/10.1515/LANGCOG.2009.011

Vigliocco, G., Ponari, M., & Norbury, C. (2018). Learning and Processing Abstract Words and Concepts: Insights From Typical and Atypical Development. *Topics in Cognitive Science*, *10*(3), 533–549. https://doi.org/10.1111/tops.12347

Vohr, B., Jodoin-Krauzyk, J., Tucker, R., Johnson, M. J., Topol, D., & Ahlgren, M. (2008). Early language outcomes of early-identified infants with permanent hearing loss at 12 to 16 months of age. *Pediatrics*, *122*(3), 535–544. https://doi.org/10.1542/peds.2007-2028

Vohr, B., Jodoin-Krauzyk, J., Tucker, R., Topol, D., Johnson, M. J., Ahlgren, M., & Pierre, L. (2011). Expressive vocabulary of children with hearing loss in the first 2 years of life: Impact of early intervention. *Journal of Perinatology*, *31*(4), 274–280. https://doi.org/10.1038/jp.2010.110

von Hofsten, C. (1989). Mastering Reaching and Grasping: The Development of Manual Skills in Infancy. In S. A. Wallace (Ed.), *Advances in Psychology* (Vol. 61, pp. 223–258). North-Holland. https://doi.org/10.1016/S0166-4115(08)60023-0

Vygotsky, L. S. (1978). *Mind in Society: Development of Higher Psychological Processes*. Harvard University Press. https://doi.org/10.2307/j.ctvjf9vz4

Vyshedskiy, A., Mahapatra, S., & Dunn, R. (2017). Linguistically deprived children: Meta-analysis of published research underlines the importance of early syntactic language use for normal brain development. *Research Ideas and Outcomes*, *3*, e20696. https://doi.org/10.3897/rio.3.e20696

Walker, E. A., Holte, L., McCreery, R. W., Spratford, M., Page, T., & Moeller, M. P. (2015). The Influence of Hearing Aid Use on Outcomes of Children With Mild Hearing Loss. *Journal of Speech, Language, and Hearing Research : JSLHR*, *58*(5), 1611–1625. https://doi.org/10.1044/2015_JSLHR-H-15-0043

Wang, X., Wang, B., & Bi, Y. (2022). *Early-life language deprivation affects specific neural mechanisms of semantic representations* (p. 2022.11.06.515336). bioRxiv. https://doi.org/10.1101/2022.11.06.515336

Wang, Y., Williams, R., Dilley, L., & Houston, D. M. (2020). A meta-analysis of the predictability of LENA™ automated measures for child language development. *Developmental Review*, *57*, 100921. https://doi.org/10.1016/j.dr.2020.100921

Watkin, P., McCann, D., Law, C., Mullee, M., Petrou, S., Stevenson, J., Worsfold, S., Ho, M. Y., & Kennedy, C. (2007). Language ability in children with permanent hearing impairment: The influence of early management and family participation. *Pediatrics*, *120*(3). https://doi.org/10.1542/peds.2006-2116

Watkins, S., Pittman, P., & Walden, B. (1998). The Deaf Mentor Experimental Project for young children who are deaf and their families. *American Annals of the Deaf*, *143*(1), 29–34. https://doi.org/10.1353/aad.2012.0098

Weisleder, A., & Fernald, A. (2013). Talking to Children Matters: Early Language Experience Strengthens Processing and Builds Vocabulary. *Psychological Science*, *24*(11), 2143–2152. https://doi.org/10.1177/0956797613488145

Weizman, Z. O., & Snow, C. E. (2001). Lexical input as related to children’s vocabulary acquisition: Effects of sophisticated exposure and support for meaning. *Developmental Psychology*, *37*(2), 265–279. https://doi.org/10.1037/0012-1649.37.2.265

Werker, J. F., Cohen, L. B., Lloyd, V. L., Casasola, M., & Stager, C. L. (1998). Acquisition of word–object associations by 14-month-old infants. *Developmental Psychology*, *34*, 1289–1309. https://doi.org/10.1037/0012-1649.34.6.1289

Werker, J. F., & Tees, R. C. (1984). Cross-language speech perception: Evidence for perceptual reorganization during the first year of life. *Infant Behavior & Development*, *7*, 49–63. https://doi.org/10.1016/S0163-6383(84)80022-3

West, K. L., & Iverson, J. M. (2017). Language learning is hands-on: Exploring links between infants' object manipulation and verbal input. *Cognitive Development*, *43*, 190–200. https://doi.org/10.1016/j.cogdev.2017.05.004

West, M. J., & Rheingold, H. L. (1978). Infant stimulation of maternal instruction. *Infant Behavior and Development*, *1*, 205–215. https://doi.org/10.1016/S0163-6383(78)80031-9

White, S. J., & White, R. E. (1987). The effects of hearing status of the family and age of intervention on receptive and expressive oral language skills in hearing-impaired infants. *ASHA Monographs*, *26*, 9–24.

Wijffels, J. (2023). *UDPipe*. https://cran.r-project.org/web/packages/udpipe/vignettes/udpipe-annotation.html#annotate-your-text

Wild, C. J., Linke, A. C., Zubiaurre-Elorza, L., Herzmann, C., Duffy, H., Han, V. K., Lee, D. S. C., & Cusack, R. (2017). Adult-like processing of naturalistic sounds in auditory cortex by 3- and 9-month old infants. *NeuroImage*, *157*, 623–634. https://doi.org/10.1016/j.neuroimage.2017.06.038

Wilson, J., & Halverson, H. M. (1947). Development of a Young Blind Child. *The Pedagogical Seminary and Journal of Genetic Psychology*, *71*(2), 155–175. https://doi.org/10.1080/08856559.1947.10533421

Winiger, A. M., Alexander, J. M., & Diefendorf, A. O. (2016). Minimal Hearing Loss: From a Failure-Based Approach to Evidence-Based Practice. *American Journal of Audiology*, *25*(3), 232–245. https://doi.org/10.1044/2016_AJA-15-0060

Winter, B., Perlman, M., & Majid, A. (2018). Vision dominates in perceptual language: English sensory vocabulary is optimized for usage. *Cognition*, *179*, 213–220. https://doi.org/10.1016/j.cognition.2018.05.008

Xu, D., Yapanel, U., & Gray, S. (2009). *Reliability of the LENA Language Environment Analysis System in Young Children's Natural Home Environment* (pp. 1–16). The

LENA Foundation. https://www.lena.org/wp-content/uploads/2016/07/LTR-05-2_Reliability.pdf

Yee, E., Chrysikou, E. G., Hoffman, E., & Thompson-Schill, S. L. (2013). Manual Experience Shapes Object Representations. *Psychological Science*, *24*(6), 909–919. https://doi.org/10.1177/0956797612464658

Yoshinaga-Itano, C., Sedey, A. L., Coulter, D. K., & Mehl, A. L. (1998). Language of early- and later-identified children with hearing loss. *Pediatrics*, *102*(5), 1161–1171. https://doi.org/10.1542/peds.102.5.1161

Yoshinaga-Itano, C., Sedey, A. L., Mason, C. A., Wiggin, M., & Chung, W. (2020). Early Intervention, Parent Talk, and Pragmatic Language in Children With Hearing Loss. *Pediatrics*, *146*(Supplement_3), S270–S277. https://doi.org/10.1542/peds.2020-0242F

Yoshinaga-Itano, C., Sedey, A. L., Wiggin, M., & Chung, W. (2017). Early hearing detection and vocabulary of children with hearing loss. *Pediatrics*, *140*(2). https://doi.org/10.1542/peds.2016-2964

Yoshinaga-Itano, C., Sedey, A. L., Wiggin, M., & Mason, C. A. (2018). Language outcomes improved through early hearing detection and earlier cochlear implantation. *Otology and Neurotology*, *39*(10), 1256–1263. https://doi.org/10.1097/MAO.0000000000001976

Yu, C., & Smith, L. (2012). Embodied attention and word learning by toddlers. *Cognition*, *125*(2), 244–262. https://doi.org/10.1016/j.cognition.2012.06.016

Yu, C., & Smith, L. B. (2007). Rapid Word Learning Under Uncertainty via Cross-Situational Statistics. *Psychological Science*, *18*(5), 414–420. https://doi.org/10.1111/j.1467-9280.2007.01915.x

Yurovsky, D., Smith, L. B., & Yu, C. (2013). Statistical word learning at scale: The baby's view is better. *Developmental Science*, *16*(6), 959–966. https://doi.org/10.1111/desc.12036

Zimmerman-Phillips, S., Robbins, A. M., & Osberger, M. J. (2000). Assessing Cochlear Implant Benefit in Very Young Children. *Annals of Otology, Rhinology & Laryngology*, *109*(12_suppl), 42–43. https://doi.org/10.1177/0003489400109S1217

Zohary, E., Harari, D., Ullman, S., Ben-Zion, I., Doron, R., Attias, S., Porat, Y., Sklar, A. Y., & Mckyton, A. (2022). Gaze following requires early visual experience.

Proceedings of the National Academy of Sciences, *119*(20), e2117184119. https://doi.org/10.1073/pnas.2117184119

Biography

Erin E. Campbell was born in Philadelphia, Pennsylvania. She completed a Bachelor’s at Towson University, graduating Magna cum Laude with degrees in Speech Language Pathology and Audiology, Deaf Studies, and Disability Studies, with minors in Linguistics and Spanish. At Duke University, she earned a master’s degree in Psychology & Neuroscience in 2021 and a PhD in Cognition and Cognitive Neuroscience in 2023. Erin received funding during these years from the National Science Foundation Graduate Fellowship Program and the Charles Lafitte Foundation. She will continue her work on perceptual experience and language acquisition as a postdoctoral researcher at Boston University.