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

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Abstract

Purpose: This study compared language input to young blind children and their sighted peers in naturalistic home settings.

Methods: Using the LENA audio recorder, naturalistic speech in the home was captured and analyzed for various dimensions of language input, including quantitative, interactive, linguistic, and conceptual features.

Results: Our data showed broad similarity across groups in speech quantity and interaction. Fine-grained analysis revealed that blind children's language environments contained more lexical diversity, longer utterances, more temporal displacement, and content words with referents that children don't interact with.

Conclusions: The findings challenge the notion that blind children's language input places them at a disadvantage and suggest instead that blind children receive rich and complex language input that can support their language development.

Introduction

The early language skills of blind children are highly variable (E. E. Campbell, Casillas, & Bergelson, submitted), with some blind children demonstrating age-appropriate vocabulary from the earliest stages of language learning (Ann Bigelow, 1987; E. E. Campbell et al., submitted; Landau & Gleitman, 1985), while others experience large and persistent language delays (E. E. Campbell et al., submitted). By adulthood, blind individuals are fluent speakers of their language and are even reported to have faster auditory and lexical processing skills than sighted adults (Loiotile, Lane, Omaki, & Bedny, 2020; Röder, Demuth, Streb, & Rösler, 2003; Röder, Rösler, & Neville, 2000). The causes of this 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? There are multiple possible contributors to the variability in language development for blind children, including characteristics of the child (e.g., visual acuity, comorbid conditions, cognitive ability, gender) as well as characteristics of the environment (e.g., access to early intervention services; school setting; caretakers tailoring interactions to their child's sensory access). Here, we compare the language environment of blind children to that of their sighted peers. In doing so, we can 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.

Why would input matter?

Among both typically-developing children and children with developmental differences, language input can predict variability in language outcomes (Anderson, Graham, Prime, Jenkins, & Madigan, 2021, 2021; Gilkerson et al., 2018; Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991; Huttenlocher, Waterfall, Vasilyeva, Vevea, & Hedges, 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** (MacLeod & Demers, 2023). Quantity of language input 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, Pittman, & Walden, 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 from just from exposure to large quantities of speech (e.g., Roseberry, Hirsh-Pasek, & Golinkoff, 2014 May-Jun), so something about the *type* of language input must matter.

The specific characteristics of that language input are perhaps even more influential

(Hirsh-Pasek et al., 2015; Rowe, 2012), although it is somewhat trickier to turn the qualitative characteristics of language input into operationalizable properties. Rowe and Snow (Rowe & Snow, 2020) divide this space into three dimensions of language input: 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 (e.g., topic diversity).

Parents' active response to their children's actions and utterances supports their learning. 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, Bannard, McGillion, Slocombe, & Matthews, 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, Brown, and Levinson (2020)] is associated with children's vocabulary and lexical processing (Rowe, 2008; Shneidman, Arroyo, Levine, & Goldin-Meadow, 2013; Weisleder & Fernald, 2013).

The linguistic characteristics of language input can be thought of in terms of which words are used and how those words 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, Hadley, & Rispoli, 2017; Huttenlocher et al., 2010; Rowe, 2012; Weizman & Snow, 2001). Likewise, the diversity and complexity of syntactic constructions in parental language input is associated both with children's vocabulary growth and structure diversity in their own productions (De Villiers, 1985; Hadley et al., 2017; Hoff, 2003 Sep-Oct; Huttenlocher, Vasilyeva, Cymerman, & Levine, 2002; Huttenlocher et al., 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, displaced, decontextualized referents improves (Bergelson & Swingley, 2013; Kramer, Hill, & Cohen, 1975; Luchkina, Xu, Sobel, & Morgan, 2020). Displaced 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, Rowe, Heller, Goldin-Meadow, & Levine, 2015; Rowe, 2012; Uccelli, Demir-Lira, Rowe, Levine, & Goldin-Meadow, 2019).

From this review, it appears that sighted children learn about the world and language simultaneously from many sources, including 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. For instance, 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, so language input may take on a larger role in the discovery of word meaning (E. E. Campbell & Bergelson, 2022). 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 for blind children relative to sighted children.

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 & Cole, 1978). Child-directed speech is one example–whereby parents speak to young children with exaggerated prosody, slower speech rate, and increased vowel clarity (Bernstein Ratner, 1984; Fernald, 1989), which is in some cases helpful to the young language learner (Thiessen, Hill, & Saffran, 2005). When interacting with infants and toddlers, parents repeat words more often than when interacting 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, Stevens, Kok, Frijns, & Rieffe, 2020; Yoshinaga-Itano, Sedey, Mason, Wiggin, & Chung, 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, Kraut, & Fussell, 2004; Grigoroglou, Edu, & Papafragou, 2016). In a noisy environment, speakers will adapt the acoustic-phonetic features of their speech with the intent 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, Paridon, & Montero-Melis, 2019). During in-lab tasks with sighted participants, participants tailor their descriptions and requests by verbally providing visually-absent cues when an object is occluded to their partner (Hawkins, Gweon, & Goodman, 2021; Jara-Ettinger & Rubio-Fernandez, 2021; Rubio-Fernandez, 2019). These results suggest that adults and even infants (Chiesa, Galati, & Schmidt, 2015; N. 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 early 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, Dunlea, & Kekelis, 1993; J. Campbell, 2003; Kekelis & Andersen, 1984; though c.f., Moore & McConachie, 1994). Studies of input to blind children in naturalistic settings 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 Nov-Dec) and colleagues 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.

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 (E. E. 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 interactivity (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).

Methods

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 $\geq$ 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 ($\pm$ 6 weeks), gender, maternal education ($\pm$ one education level: less than high school diploma, high school diploma, some college / Associate's, Bachelor's, graduate school), and number of siblings ($\pm$ 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 1 for sample characteristics.

Table 1

Demographic characteristics of the blind and sighted samples

Group	Age (months)	Sex	Race	Number of Older Siblings	Maternal Education Level	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: 0%	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%	

Recording Procedure

For the recording portion of the study, caregivers of participating infants received a LENA wearable audio recorder and vest (Ganek & Eriks-Brophy, 2016; 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 these pauses to a minimum. Actual recording length ranged from 8 hours 17 minutes to 15 hours 59 minutes (Mean: 15 hours 16 minutes).

Processing

The audio recordings were first processed by LENA proprietary software (Xu, Yapanel, & Gray, 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. The process outputs a codeable ELAN file (.eaf, Brugman & Russel, 2009). 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 the annotation clip. Each file therefore contains 30 minutes of coded recording time and 75 minutes of total time listened. Because these segments were sampled randomly, across participants roughly 0% 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, Gautheron, & Cristia, 2021).

Therefore, we also 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, Bousbib, Bredin, Dupoux, & Cristia, 2021) which identified all human speech in the recording. The entire recording was then broken into 2-minute chunks marked out at zero-second timestamps (e.g. 00:02:00.000 to 00:04:00.000). Each of these chunks was ranked highest to lowest by the total duration of speech contained within the boundaries, and we annotated the highest-ranked 5 segments of each recording. These high volubility segments allowed us first to characterize features of the language as proportions of the linguistic input children receive, and second, 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, Amatuni, Dailey, Koorathota, & Tor, 2019). In sum, we have 30 minutes of randomly sampled input and 10 minutes of high-volubility input (40 minutes total) were annotated per child.

Annotation

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). Prior to annotating lab data, annotators are trained on previously coded samples of child recordings and are required to reach 95% overall agreement with the gold standard version. For more information about this annotation scheme, please see the ACLEW homepage. Following the first pass, all files were reviewed by a highly-trained "superchecker" to ensure the consistency of annotations.

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 based on the addressee of each utterance: speech directed to a child; adult-directed speech; speech directed to both an adult and a child; speech directed to pets or other animals; speech with an unclear addressee; or speech directed towards a recipient that doesn't fit into another category (e.g., voice control of Siri or Alexa, prayer to a metaphysical entity).

Extracting Measures of Language Input

To go from our dimensions of interest (quantity, interactiveness, 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 interactiveness 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 2.

Quantity.

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; Segments that the LENA algorithm identifies as "far", "child", or "overlapping", do not contribute to this count (Xu et al., 2009). Validation work suggests that this automated count correlates strongly with word counts derived from manual annotations (r = .71 – .92, Lehet, Arjmandi, Houston, & Dilley, 2021), but Lehet et al. (2021) and colleagues find that the amount of error may vary substantially across families. Compared to short samples that they had manually transcribed and counted, LENA's AWC estimate ranged from undercounting words by 17% to overcounting words by 208% (Lehet et al., 2021). Perhaps reassuringly however, meta-analytic work finds that AWC is associated with children's language outcomes across developmental contexts (e.g., autism, hearing loss, Wang, Williams, Dilley, & Houston, 2020). Because the recordings varied in length (8 hours 17 minutes to 15 hours 59 minutes), we normalized AWC by dividing by recording length [1].

Manual Word Count.

[1] 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.

We also compare a manual count of speech in the children's environment. Manual word count is simply the number of intelligible words in our transcriptions of 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. To try to get a representative estimate of the amount of talk in a children's environment, we use the random samples only for this measure.

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.

Interactivity.

Conversational Turn Count.

One commonly used and easily-extracted metric of communicative interaction (e.g., Ganek & Eriks-Brophy, 2018; Magimairaj, Nagaraj, Caballero, Munoz, & White, 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, Hippe, & Kuhl, 2021). Still, this measure correlates moderately well with manually-coded conversational turns (Busch, Sangen, Vanpoucke, & van Wieringen, 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 biased towards either groups. Conversational turn count is calculated over the entire recording, but to normalize for recording length, we divided this by recording length.

Proportion of Child-Directed Speech.

Our other measure of interactivity 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. To try to get a representative measure of child-directed speech in the environment overall (Cychosz, Villanueva, & Weisleder, 2021), we use the random samples only for this calculation.

Linguistic Features.

Type-Token Ratio.

As in previous work (Montag, Jones, & Smith, 2018; Pancsofar & Vernon-Feagans, 2006; e.g., 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). For each child, type-token ratio is the average of the type-token ratios for each of the bins in their input.

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 remain consistent for individual caretakers, in and out of lab settings (Stevenson, Leavitt, Roach, Chapman, & Miller, 1986). Each utterance was tokenized into morphemes using the 'morphemepiece' R package (Bratt, Harmon, & Learning, 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 (n =), which yielded a intra-class correlation coefficient of 0.94 agreement with the udpipe approach ($p < .001$), indicating high consistency.

Conceptual Features. Our analysis of the conceptual features aims to measure whether the extent to which language input centers around the *"here and now"*: objects/events/people that are currently present/occurring vs. displaced objects/events. Prior work has quantified such *here-and-now*ness by counting object presence co-occurring with a related noun label (P. A. Ganea & Saylor, 2013; Harris, Jones, Brookes, & Grant, 1986; Moore & McConachie, 1994; e.g., Osina, Saylor, & Ganea, 2013). The audio format of our data make 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 do this by comparing 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?

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, Rohlfing, Lüke, Liszkowski, & Ritterfeld, 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.

CBOI distribution.

Next, we measured whether the distribution of Child-Body-Object Interaction (CBOI) rating differed across groups (Muraki, Siddiqui, & Pexman, 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.

Proportion of highly visual words.

In addition to these two more traditional measures of decontextualized language, we include one measure that is uniquely decontextualized for the blind children relative to their sighted matches: 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, Connell, Brysbaert, Brand, & Carney, 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) across all modalities were re-categorized as *amodal*, and words whose ratings were distributed across modalities (perceptual exclusivity < 0.5) 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.

Results

Measuring Properties of Language Input

Our study assesses whether language input to blind children is different from the language input to sighted children, along the dimensions of quantity, interactivity, 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 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 3.

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 word token count from our manual annotations. Shapiro-Wilks tests indicated that both of these variables were normally distributed (ps > .05). Because the quantity analysis consists of two statistical tests, our Benjamini-Hochberg critical values were $p < 0.03$ 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 words$_{\text{blind}}$, 238–804 words$_{\text{sighted}}$), blind and sighted children do not differ in language input quantity ($t() = 163$, $p = .243$). 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 1.

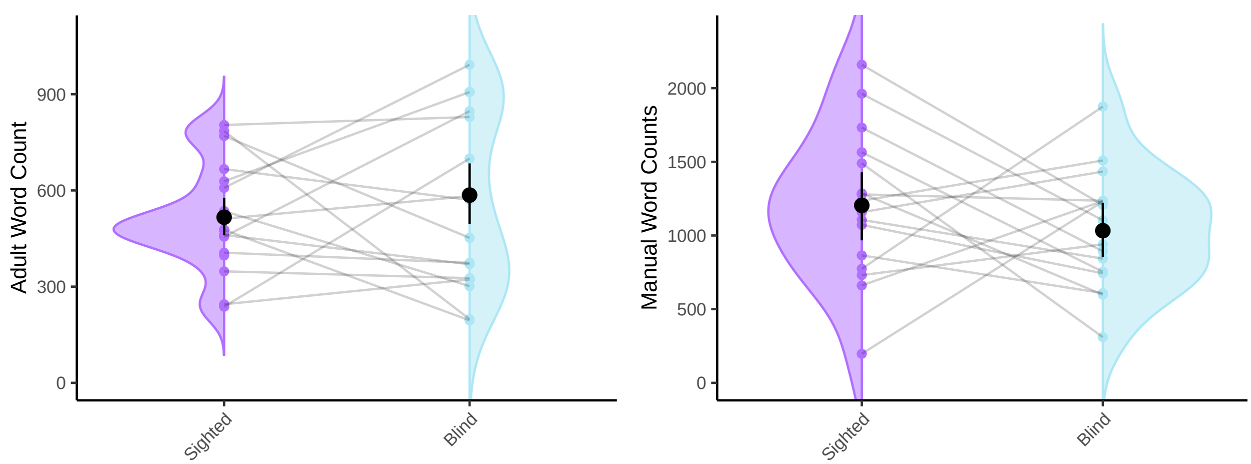


Figure 1. Comparing LENA-generated adult word counts (left) and transcription-based word counts in the input of blind and sighted children. Each dot represents the estimated number of words in one child's recording.

Interactivity. Next, we ask whether the language environments of blind vs. sighted participants 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 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 = 0.06, p = .952) or in conversational turn counts to blind children versus to sighted children .

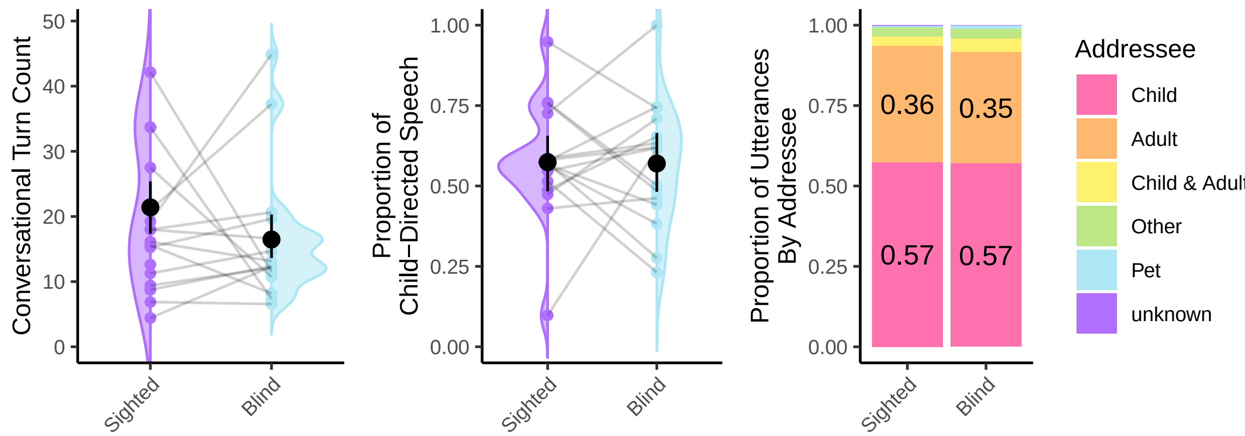


Figure 2. Comparing LENA-generated conversational turn counts (left) and proportion of utterances in child-directed speech (center). Each dot represents one child's recording. The full breakdown by addressee is shown in the rightmost panel.

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. Results indicated that 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 3).

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

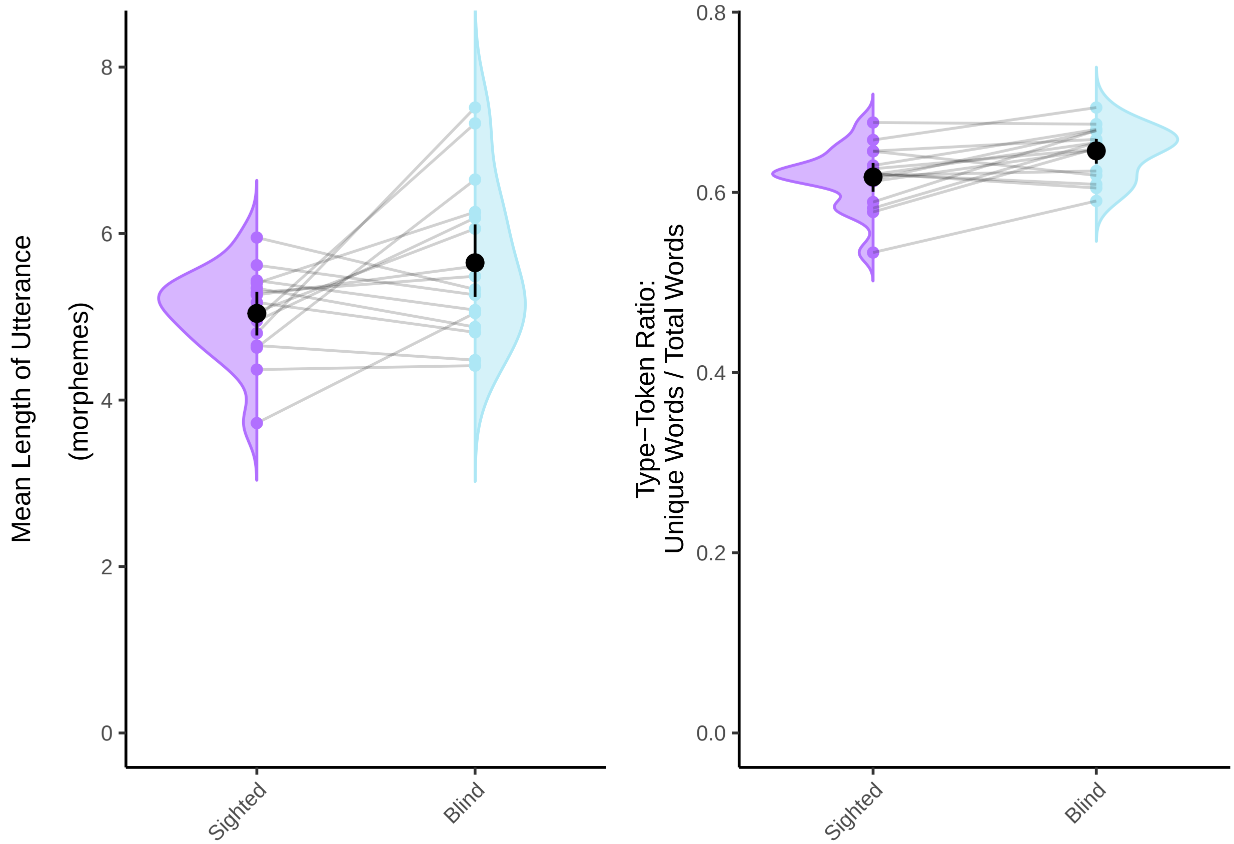
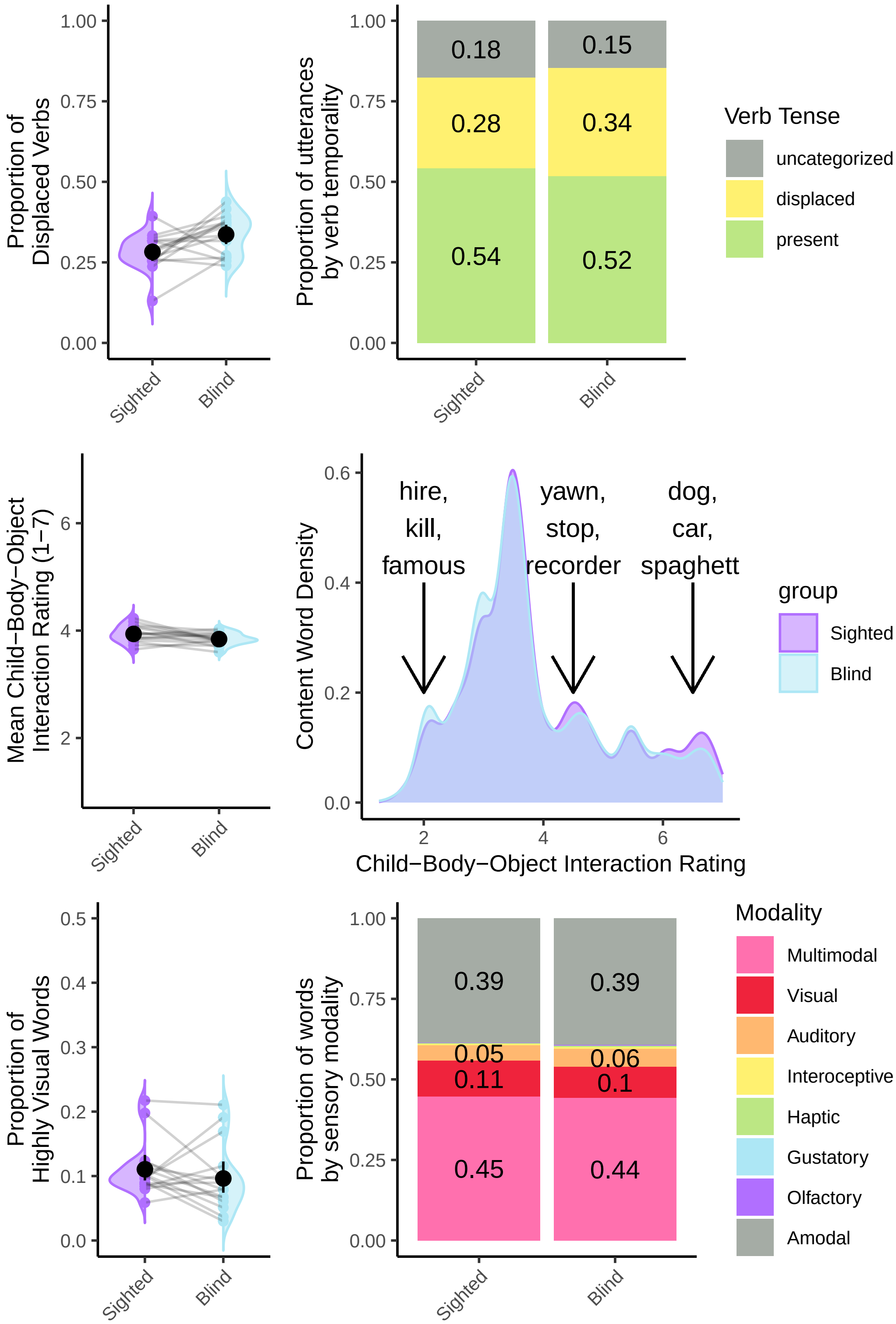


Figure 3. Comparing linguistic features: Mean length of utterance (left); each dot represents one speaker. Type-token ratio (right). Each dot represents one child's recording.

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. 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 **??**. 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).


Proportion of Displaced Verbs
1.00
0.75
0.50
0.25
0.00
Sighted
Blind
Proportion of utterances by verb temporality
0.18
0.15
0.28
0.34
0.54
0.52
Verb Tense
uncategorized
displaced
present
Mean Child−Body−Object Interaction Rating (1−7)
6
4
2
Content Word Density
0.6
0.4
0.2
0.0
hire, kill, famous
yawn, stop, recorder
dog, car, spaghett
Child−Body−Object Interaction Rating
group
Sighted
Blind
Proportion of Highly Visual Words
0.5
0.4
0.3
0.2
0.1
0.0
Proportion of words by sensory modality
0.39
0.39
0.05
0.06
0.11
0.1
0.45
0.44
Modality
Multimodal
Visual
Auditory
Interoceptive
Haptic
Gustatory
Olfactory
Amodal

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 to capture naturalistic speech in the home. We found that across along the dimensions of quantity and interaction dimensions of language input, parents largely 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.

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.

Interactivity

We quantified interactivity 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 (Pérez-Pereira & Conti-Ramsden, 2001; Rowland, 1984; Andersen et al., 1993; Grumi et al., 2021; Kekelis & Andersen, 1984;, Moore & McConachie, 1994; Preisler, 1991). 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 video recordings 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[2] , prior research may have artificially suppressed blind children's initiation of interactions. Even naturalistic observer-free video-recordings appear to inflate aspects of parental input, relative to daylong 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 less interaction (Nagayoshi et al., 2017; Sally J. 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, Mayfield, & Baker, 1997; Preisler, 1991; Sally J. Rogers & Puchalski, 1984). We can't help but wonder: are visual markers of social interaction the right yardstick to measure blind children against?

[2] 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).

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 coding schemes.

Linguistic Features

Along the linguistic dimension, we measured type-token ratio and mean length of utterance. Parents of children with disabilities (Chernyak, n.d.; including parents of blind children! e.g., FamilyConnect, n.d.) are often advised to use shorter, simpler sentences with their children, and correspondingly, previous work finds that parents of children with disabilities tend to find that parents *do* use shorter, simpler utterances (e.g., Down syndrome, Lorang, Venker, & Sterling, 2020; hearing loss, Dirks et al., 2020). We had therefore expected to observe shorter utterances and less lexical diversity. By contrast, 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 scores (Anderson et al., 2021; Hsu et al., 2017; Huttenlocher et al., 2010; Rowe, 2012; Weizman & Snow, 2001). Perhaps fortunately then, it seems that parents of blind children are not following advice to simplify the input.

Conceptual Features

Relative to other aspects of language input, the conceptual dimension varied most across groups. 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; J. Campbell, 2003; Kekelis & Andersen, 1984; Moore & McConachie, 1994; Urwin, 1984). This aspect of language input is of particular interest because, for sighted children, decontextualized language in the input is associated with children's own use of decontextualized language, and early reports suggest that blind children's own use of decontextualized language develops later than sighted children's[3] (A. 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. One possible explanation is that because children have less access to immediate visual cues, caregivers might instead 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

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

across discourse.

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 hypothesis. Rather, we find far more similarity across groups than differences, and these differences were modest in magnitude. 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.

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, 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, de Carvalho, Trueswell, & Christophe, 2021; Babineau, Havron, Dautriche, de Carvalho, & Christophe, 2022; E. E. Campbell & Bergelson, 2022).

Returning to the larger equation of language development, blind and sighted infants differ in their access to perceptual input, and we have shown that language input is different along only a few axes: conceptual features, where language and the perceptual world interact, and complexity, with blind children hearing slightly longer utterances and more lexically-diverse input. Initial vocabulary delays in blind children may then primarily be a result of the conflict between their lack of visual access and the majority-visual cues to early "brute-force" word learning (e.g., shared gaze, pointing, visual perception of referents). It could be precisely this 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.

Conclusion

In summary, our study compared language input in homes of 15 blind and 15 sighted infants/toddlers. 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 importance of recognizing and appreciating the unique language experiences of blind children. Future research could investigate how these input differences impact the language development and cognitive abilities of blind and sighted children alike.

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Table 2

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 (WC)	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	Manual + NLP parsing	Random + High Volume	Average number of morphemes per utterance
Proportion of Temporally Displaced Verbs (Prop. Displaced)	Manual + NLP tagging	Random + High Volume	Proportion of verbs that refer to past, future, or hypothetical events
Child-Body-Object Interaction Ratings (CBOI)	Manual + NLP 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	Manual	Random + High Volume	Proportion of words in the input with high visual association ratings and low ratings for other perceptual modalities

Table 3

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/hour	1033 words/hour	.243	
Manual Word Count	Paired t-test	Blind ~ Sighted	2065 words/hour	2409 words/hour	.255	
Prop. Child-Directed Speech	Paired Wilcoxon test	Blind ~ Sighted	33 turns/hour	43 turns/hour	.952	
Conversational Turn Count	Paired t-test	Blind ~ Sighted	0.57	0.57	.096	
Type-Token Ratio	Paired t-test	Blind > Sighted	0.65 words/hour	0.62 words/hour	.040*	*
Mean Length of Utterance	Paired t-test	Blind > Sighted	5.65 morphemes	5.04 morphemes	.024*	*
Prop. Displaced	Paired t-test	Blind > Sighted	0.34	0.28	.014*	*
Child-Body-Object Interaction	Kolmogorov–Smirnov test	Blind < Sighted	3.84 / 7	3.94 / 7	< .001*	*
Prop. Visual	Paired Wilcoxon test	Blind ~ Sighted	0.1	0.11	.632	