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# THRIVING IN A CHANGING WORLD

RESEARCH PROCEEDINGS

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Children's task is essentially the same regardless of the number of languages they are learning: They need to map meaning to form, convey, or decode a linguistic message. At the same time, bilingual children are not the sum of two monolinguals and dealing with two languages creates situations that do not arise in the learning of just one language. Issues of language differentiation and cross-linguistic interaction are core to the development of bilingual children from their early sound discrimination to the production of complex sentences. Evidence from the role of relative amount of language exposure, individual differences in processing efficiency, and the shared nature of syntactic representations contributes to our understanding of different stages of language development in young bilinguals.

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## Pragmatic Development in Typically Hearing Children

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Pragmatics is the domain of language that relates linguistic forms to the people using them. The development of pragmatics starts from birth with caregiver-infant exchanges and builds right up to understanding functionally complex forms of language including sarcasm. This brief overview will consider the pragmatic developments that come with the discovery of prelinguistic communication, words, sentences, and supra-sentential structures as well as different types of nonliteral language. The focus will be on the developmental trajectory of typically hearing children learning a spoken language, although some signposts to research with deaf and hard of hearing (DHH) children learning spoken and/or signed languages will be given along the way. As we will come to see, pragmatic development depends critically on accessing interaction with others in order for children to become effective communicators who can build on their confidence at each stage in order to reach the next.

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Krystal L. Werfel<sup>a</sup> and Emily Lund<sup>b</sup> | <sup>a</sup>*University of South Carolina*; <sup>b</sup>*Texas Christian University*

The ELLA Study is a longitudinal investigation of language and literacy acquisition in children with hearing loss. The total sample includes 100 children with hearing loss and 60 children with typical hearing. Findings to date have shown that children with hearing loss exhibit delays across many early language and literacy skills relative to their peers with typical hearing. Additionally, children's engagement with books and entry in early intervention by 6 months of age are associated with higher language and emergent literacy outcomes.

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## Benefits to Patients from Binaural Hearing: Spatial Perception and Cognitive Load

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Binaural hearing is critical for everyday communication. In the past two decades there has been a major shift towards providing cochlear implants (CIs) in both ears, recognizing that patients can potentially benefit from having the ability to localize sound and hear speech in noise. However, CIs were not designed as coordinated devices that can easily capture binaural cues. The Binaural Hearing and Speech Lab at the University of Wisconsin-Madison focuses on three important areas of study: sound localization, hearing speech in noise, and listening effort. This paper provides an overview of how our lab is assessing and working towards true binaural hearing for CI users.

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# Language Development in Bilingual Children: From Sounds to Sentences

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## ABSTRACT

*Children's task is essentially the same regardless of the number of languages they are learning: They need to map meaning to form, convey, or decode a linguistic message. At the same time, bilingual children are not the sum of two monolinguals and dealing with two languages creates situations that do not arise in the learning of just one language. Issues of language differentiation and cross-linguistic interaction are core to the development of bilingual children from their early sound discrimination to the production of complex sentences. Evidence from the role of relative amount of language exposure, individual differences in processing efficiency, and the shared nature of syntactic representations contributes to our understanding of different stages of language development in young bilinguals.*

## WHO ARE BILINGUAL CHILDREN?

Studying language development in bilingual children entails a number of nontrivial challenges due to the inherent heterogeneity of the population. The societal context in which children grow up can vary substantially, ranging from situations in which two languages have official status and there is educational support for both (e.g., Welsh and English in Wales, Basque and Spanish in the Basque Country, Catalan and Spanish in Catalonia, French and English in Canada) to contexts in which children live in *de facto* to local bilingual communities and can access bilingual education to some extent, although only one of the languages is official recognized (e.g., Spanish-English bilingual programs in the United States) to pockets of bilingual communities or individual bilingual families in which there is no formal educational support for the nonofficial language (e.g., Punjabi speakers in Australia or Polish speakers in the United Kingdom). In situations where children speak a language at home that is not the dominant language of the larger (national) society, that language is considered a heritage language.

Household composition and parents' own bilingual status can differ dramatically, giving rise to different family constellations of native and non-native speakers that have consequences for bilingual language development (Place & Hoff, 2011). The presence of two parents who are speakers of a heritage language increases the chances that their children will learn the heritage language alongside the majority language, as opposed to when only one parent is a speaker of the heritage language (De Houwer, 2007; Yamamoto, 2001). Input from several different speakers is more conducive to language development than the same amount of input from a smaller number of speakers; this has been shown to be the case for bilingual

2-year-olds' vocabulary and grammatical complexity (Place & Hoff, 2011). Another aspect of the input that plays a significant role in predicting children's language skills is the nativeness of the input: Input from non-native speakers with limited proficiency is less supportive of language development than input that comes from native speakers (Hoff & Core, 2013). Birth order and the presence of older siblings also contribute to the makeup of a child's relative exposure to two languages. Younger siblings are more likely to be exposed to the majority language through their older siblings (Ellis et al., 2002), and parents are more likely to switch to the majority language in the presence of older siblings, thus reducing the amount of heritage language input.

The age of first exposure to two languages also adds to the environmental diversity among bilingual children, with some children qualifying as simultaneous bilinguals if they are exposed to two languages from birth or soon after, and others as sequential bilinguals (or cases of early second language acquisition) when exposure to one language chronologically precedes the exposure to the other language (see Serratrice, 2018, for a discussion of the differences between bilingual, first-language acquisition, and early, second-language acquisition).

Assuming that the fundamental operation of language learning is driven by the child's need to fulfil a communicative intent, their task is the same regardless of the language they need to learn. What is different is the way in which each language packages the form-function mapping, and this variation is also subject to a typological distance metric whereby some language combinations (e.g., Spanish-Catalan) will be considerably closer than others (e.g., English-Mandarin), a factor that has implications for language learning. For example, the relative distance in a bilingual's language pair will affect the number of cognates

across the two languages—that is, words that have the same (orthographic) phonological forms cross-linguistically, such as *gat*-Catalan, *gato*-Spanish—and hence the extent to which lexical learning proceeds more or less in parallel. According to parental estimates in one recent study, almost one-third of the total vocabulary size of 18-month-old infants learning two closely related languages (like Spanish-Catalan) is accounted for by form-identical cross-language words (Bosch & Ramon-Casas, 2014).

## DISCRIMINATING LANGUAGES AND SOUNDS

Well before children utter their first words they have already learnt a great deal about their linguistic environment. For children who are born to a context in which two languages are spoken, their environment will necessarily encompass knowledge in both languages.

Monolingual newborns can discriminate between the native language, to which they have been exposed in utero, and a language from another rhythmic class, but they cannot discriminate languages from the same rhythmic class (Mehler et al., 1988). Studies on newborns who have been exposed to two languages from different rhythmic classes in utero show that prenatal bilingual exposure affects infants' preferences soon after birth. Using the High Amplitude Sucking paradigm, Byers-Heinlein and colleagues (2010) tested the preference of 15 newborns from an English monolingual background and 15 infants born to English-Tagalog bilingual mothers. Unlike monolingual newborns, who displayed a significant preference for English, the infants of bilingual mothers were equally interested in Tagalog and English, consistent with their prenatal experience of both languages. In addition, the study showed that the bilingual children could reliably discriminate between Tagalog, a syllable-timed language, and English, a stressed-timed language, presumably on the basis of interclass rhythmic differences.

Although there is evidence that bilingual infants can discriminate between languages from different rhythmic classes, it is less clear whether they can also discriminate between languages that belong to the same rhythmic class and whether they do so on the basis of segmental (i.e., phonemic, phonotactic differences) or rhythmic information (i.e., the distribution of vocalic and consonantal intervals and the variability of consonantal intervals). Spanish-Catalan 4- and 5-month-olds can reliably distinguish between these two syllable-timed languages (Bosch & Sebastián-Gallés, 2001), but in this language pair infants have access to both segmental and rhythmic cues and therefore it is not clear which type of cue they rely on. At the age of 3.5 months, Basque-Spanish bilingual infants can reliably discriminate between their two languages on the basis of intra-class rhythmic differences alone (Molnar et al., 2014).

Molnar and colleagues (2014) used low-pass filtered Basque and Spanish speech that prevented access to segmental cues while preserving the rhythmic characteristics that distinguish Spanish from Basque: The distribution of vocalic intervals, the variability of consonant intervals, and the intensity and duration of stressed vowels carrying phrasal prominence. By the age of 3.5 months, bilingual exposure determines infants' ability to discriminate between their two languages on the basis of supra-segmental acoustic cues. Whether this ability is already present at birth, or whether additional language exposure is necessary for intra-class distinction, is not yet known.

While it appears that bilingual infants can rely on rhythmic and prosodic information for language discrimination, we know considerably less about how the bilingual experience affects phonemic learning. Research on monolingual infants has shown that children are born 'universal learners' with the ability to discriminate between phonetic units in any language, not just their environmental language (Eimas et al., 1971). By the end of the first year of life, this ability is greatly reduced and children's sensitivity to non-native phonemic contrasts is on the wane, while their ability to discriminate phonemic contrasts in the ambient language is fine-tuned (Werker & Lalonde, 1988). This narrowing down of phonemic discrimination is instrumental to lexical development as it allows children to focus on the contrasts that are meaningful and relevant for the language that they are in the process of learning. The findings are mixed for bilingual infants, and whether they follow the same developmental trajectory as monolinguals when it comes to phonemic discrimination is not yet clear. Some studies report bilingual-monolingual developmental differences with bilingual children going through a U-shaped learning curve where they are unable to discriminate vowel or consonant contrasts in one of their languages that they successfully identified at a younger age (Bosch & Sebastián-Gallés, 2003). Dealing with two languages entails more complex and variable input and requires specific perceptual reorganization processes. These extra processing demands may account for bilingual children's temporary inability to operate some phonetic distinctions. Other studies have shown that bilingual children can discriminate phonemic contrasts in both of their languages throughout their first year of life and beyond (Sundara et al., 2008; Sundara & Scutellaro, 2011), while monolinguals are unable to discriminate non-native contrasts past the age of 6–8 months (Burns et al., 2007). Methodological differences and variation in language combinations and phonemes tested are at least partly responsible for these discrepant results.

Behavioural and brain studies with monolingual infants have repeatedly shown a negative correlation between the ability to discriminate native and non-native contrasts, and a positive correlation between the discrimination of native contrasts and

later language development (Kuhl et al., 2005; Tsao et al., 2004). According to Kuhl (2004), early phonetic learning in the native language results in the commitment of neural networks that are dedicated to coding language-specific contrasts. This early neural commitment facilitates subsequent learning of patterns that are consistent with those that the infant has already learned (i.e., native contrasts) and it filters out those that do not confirm to the familiar patterns (i.e., non-native contrasts). This special relationship between early speech perception in the second half of the first year of life and later lexical learning depends on the ability to perceive phonetic distinctions and to successfully associate a sound pattern with a lexical item. An individual infant with advanced speech perception skills should therefore show advanced word learning skills. Infants' early phonemic discrimination abilities have important consequences for later word learning in a complex interaction with language exposure. Word learning is clearly more than just the recognition of a sequence of phonemes in the speech stream, but the ability to isolate discrete speech sounds is a clear prerequisite for lexical learning.

### WORD LEARNING: PROCESSING EFFICIENCY, LANGUAGE EXPOSURE, AND LEXICAL ACQUISITION

Word learning is a central aspect of linguistic development and an entry-level key to cracking the form-meaning mapping that is central to human communication. Vocabulary, specifically its size, is a good predictor of later language and literacy development, and the vast literature on word learning reflects the centrality of the lexicon in acquisition. Vocabulary size has also been linked to young children's speed of processing—that is, the speed with which they can accurately recognize a target word (Fernald et al., 2006)—and to the amount of language exposure (Weisleder & Fernald, 2013).

One of the methods researchers have successfully employed to study the mechanism of word learning is the listening while looking (LWL) paradigm. Children's eye gaze is tracked as they listen to a prompt that asks them to focus on one of two images on a screen (e.g., "Look at the ball!" when presented with a picture of a ball and a picture of a toy wagon). The speed with which children start looking at the relevant referent of a word in a lexical recognition task in the LWL procedure is a proxy for their lexical processing efficiency: The more efficient children are, the faster they turn their gaze to the target mentioned in the prompt. Research addressing real-time lexical recognition using the LWL paradigm has repeatedly uncovered a link between infants' and young children's lexical processing efficiency and their vocabulary size in different languages, in both monolingual and bilingual populations (Fernald et al., 2013; Hurtado et al., 2008; Hurtado et al., 2014; Legacy et al., 2016; Marchman et al., 2010). Children who are efficient at recognizing words in the speech stream have a clear advantage in avoiding a

processing bottleneck. The faster and more accurately children process words as they hear them, the better they will be in parsing the input beyond word level and the more efficient they will be at making sense of larger language constituents.

At the same time, the more words children know, the faster and more accurate they will be at recognizing them, so the relationship between lexical processing efficiency seems to be bidirectional in nature. In the case of a monolingual child, it is difficult to tease apart processing skills from input, as keeping processing skills constant and varying quantity and quality of input for one individual child is not really an option. This is where studying the relationship in bilingual children can provide a more definitive answer. If lexical processing efficiency is dependent on the opportunities afforded by the input to encounter words and to practice segmentation and lexical recognition skills, then there should be a significant language-specific relationship between the two. This is precisely what Hurtado and colleagues (2014) reported in a sample of 37 bilingual Spanish-English children tested in a LWL paradigm at 30 and 36 months of age. First, relative exposure measured through a parental interview was linked with children's relative vocabulary size, so that children who had more exposure to Spanish than English knew more words in Spanish than English. The two other sets of results from the study are more novel and particularly relevant in teasing apart the relationship between processing skills, exposure, and vocabulary size. Relative lexical processing efficiency in the children's two languages was linked to children's relative vocabulary knowledge in their two languages: Children who knew more words in Spanish compared to English were faster to access words in Spanish than in English. The language-specific relationship between word knowledge and processing suggests that children's skills at lexical recognition are not just a child-internal factor that transcends their linguistic environment, but they are intimately related to the input they need to process. Children that had more exposure to Spanish than English were relatively more efficient at recognizing words in Spanish than in English, and as a result had a comparatively larger vocabulary in Spanish than in English.

Recent research with bilingual infants and young children in the second and third year of life has consistently shown a strong relationship between relative amount of input and vocabulary size, a finding that is consistent with the results in the monolingual literature where input is measured in absolute rather than relative terms. More importantly it is becoming clear that although children come to the language learning task endowed with a set of processing skills, these are in turn shaped by the linguistic environment they have access to. The language-specific nature of the link between relative amount of exposure and relative lexical processing efficiency is particularly illuminating in this respect and a concrete example of how research with

bilinguals can inform our broader understanding of language learning mechanisms in general.

### SHARED SYNTACTIC REPRESENTATIONS IN LATER BILINGUAL DEVELOPMENT

Theoretical models of syntactic representations in bilingual language acquisition have changed considerably over the last 40 years, moving from a one-system account with no initial syntactic differentiation (Volterra & Taeschner, 1978), to a two-system model where bilingual children develop language-specific syntactic representations from the start (Genesee, 1989), to the hypothesis of early syntactic differentiation alongside pockets of systematic cross-linguistic influence, i.e., instances in which morpho-syntactic structures that belong to language  $\alpha$  are used in language  $\alpha$  in contexts that are either ungrammatical (Hulk & Müller, 2000) or discourse-pragmatically inappropriate (Paradis & Navarro 2003; Serratrice et al., 2004).

The very existence of cross-linguistic influence requires a model of bilingual language representation and processing that can do justice to the existence of forms that are (largely) unattested in monolingual acquisition. One way to understand cross-linguistic influence in bilingual speakers is through the hypothesis of shared syntax, i.e., by accepting that the bilingual language architecture must include shared syntactic representations (Hartsuiker et al., 2004; 2016). This argument has been made by psycholinguists on the basis of evidence coming from studies of syntactic priming (Bernolet et al., 2007; Desmet & Declercq, 2006; Kantola & van Gompel, 2011; Loebell & Bock, 2003). The rationale behind syntactic priming is that the processing of a syntactic structure—either in comprehension or in production—facilitates its subsequent use (Bock, 1986), a hypothesis for which there is now a great deal of support in studies of monolingual and bilingual adults (for a recent review, see Bernolet & Hartsuiker, 2018).

There is likewise robust evidence that monolingual children are susceptible to syntactic priming (Savage et al., 2003; Shimpi et al., 2007; Messenger et al., 2012; Peter et al., 2015). The extent to which bilingual children are also likely to be syntactically primed within and across languages is less clear as there are only a handful of studies that have investigated the question so far (Gámez & Vasilyeva, 2020; Hsin et al., 2013; Hervé et al., 2016; Vasilyeva et al., 2010).

The outcome of priming is the (re)use of a structure that has been recently processed in comprehension or in production and when this happens across languages, in the case of a bilingual speaker, one of two outcomes are possible. If there is structural, semantic, and pragmatic overlap for the structure in question in the two languages, then the result will essentially be less effortful processing. The alternative is a primed structure that is either ungrammatical or semantically/pragmatically suboptimal. When

there is virtual complete overlap across languages, the outcome of the process will be undiscernible. For example, if an Italian-English speaker encounters the following sentence while reading the paper: *The man was run over on the pedestrian crossing* and then proceeds to use a similar passive construction in Italian: *Mia sorella è quasi stata investita sulle strisce l'altro giorno* 'My sister was almost run over on a pedestrian crossing the other day', there is no obvious way in which this perfectly grammatical and pragmatically appropriate Italian sentence would stand out in any way as being affected by English. Conversely, if the same Italian-English speaker were on the phone to an English-speaking friend asking: *Shall we drive or walk to the cinema tonight?* and then were to utter the following Italian translation to an Italian-speaking friend: *Guidiamo o camminiamo al cinema stasera?*, there is a clear sense in which this sentence stands out as being affected by what the bilingual speaker has just heard in English and by the way in which English packages manner of motion on the verb differently from Italian. Although verbs of manner of motion like *guidare* (drive) or *camminare* (walk) do exist in Italian, Italian is a verb-framed language where the encoding of manner of motion does not tend to be specified on the verb. So a more appropriate Italian translation would be *Andiamo in macchina o andiamo a piedi al cinema stasera?* 'Do we go on foot or do we go by car to the cinema tonight?' In this case, hearing a sentence in English including two verb phrases containing manner of motion verbs primes the use of an Italian sentence also containing two verb phrases with manner of motion verbs instead of the more appropriate use of a sentence where manner of motion is specified in a prepositional phrase rather than in the verb phrase.

The few studies that have used syntactic priming to investigate shared syntactic representations in bilingual children have targeted children around the age of 5 years: Three of the studies have focused on constructions that are syntactically grammatical and equally discourse-appropriate in both languages (passives in the English and Spanish of Spanish-English bilinguals, Vasilyeva et al., 2010, Gámez & Vasilyeva, 2020; double object and prepositional object dative constructions in the Norwegian of Norwegian-English bilinguals, Wolleb et al., 2018), while the remaining two have focused on a construction that is only grammatical or pragmatically appropriate in one of the two languages (Hervé et al., 2016; Hsin et al., 2013). Overall, four of the five studies report significant priming effects across languages, thus showing that, even in young children, syntactic structures can be shared, although Vasilyeva and colleagues (2010) only found a significant priming effect from Spanish to English. Hervé and colleagues (2016) did not use cross-linguistic priming as such, but primed children with left-dislocations, sentences where a subject-noun phrase is followed by a resumptive pronoun, which were pragmatically appropriate in French but not in English (e.g. *Blue and Linda, ils se lavent les mains/Blue and Linda, they are washing their hands*).

Although Hervé and colleagues (2016) did not find that the bilingual 4- to 5-year-olds were primed to produce pragmatically inappropriate dislocations in English following a left dislocation in the prime, overall there was a significant, positive relationship between the amount of exposure in French and the overall number of left dislocations they produced in English—not just following a dislocated prime. This finding is preliminary evidence that tolerance for a structure that is not pragmatically appropriate increases as a function of exposure to another language in which the structure is indeed pragmatically appropriate.

Finally, the only study so far to prime bilingual children across languages with a construction that has a different word order in the two languages (post-nominal adjective-noun constructions in Spanish, e.g., *El libro abierto*, and pre-nominal in English, e.g., *The open book*), found that children could indeed be primed to produce a word order that is ungrammatical in Spanish (e.g., *El abierto libro*) after hearing the same order which is grammatical in English (e.g., *The big book*). Serratrice (2007) first hypothesised that cross-linguistic interference that results in either ungrammatical or pragmatically suboptimal constructions could be thought of as a case of cross-linguistic priming, an argument that was made in connection with the inappropriate selection of third-person pronouns in Italian by English-Italian 8-year-olds in contexts where a null pronoun would have been more pragmatically appropriate.

Further research with bilingual children over time will also allow researchers to take a much-needed developmental perspective as it is becoming ever clearer that the way in which representations, processing, and input interact must be viewed in a dynamic perspective.

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# Pragmatic Development in Typically Hearing Children

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## ABSTRACT

*Pragmatics is the domain of language that relates linguistic forms to the people using them. The development of pragmatics starts from birth with caregiver-infant exchanges and builds right up to understanding functionally complex forms of language including sarcasm. This brief overview will consider the pragmatic developments that come with the discovery of pre-linguistic communication, words, sentences, and supra-sentential structures as well as different types of non-literal language. The focus will be on the developmental trajectory of typically hearing children learning a spoken language, although some signposts to research with deaf and hard of hearing (DHH) children learning spoken and/or signed languages will be given along the way. As we will come to see, pragmatic development depends critically on accessing interaction with others in order for children to become effective communicators who can build on their confidence at each stage in order to reach the next.*

## WHAT IS PRAGMATICS?

Language is a powerful tool that we use to engage with other people, talk about the world around us, share thoughts and feelings, and coordinate activities. In our language toolkit we have all sort of different tools, or linguistic and para-linguistic forms (words or signs, grammatical structures, connective devices, prosodic contours, and co-speech gestures). When we think about language learning, we're thinking about children learning how these different forms are used to perform certain functions—to talk about the world. There are three important elements here—the linguistic forms, the world, and the language users—and these make up Morris' (1938) semiotic triangle as follows (Figure 1).

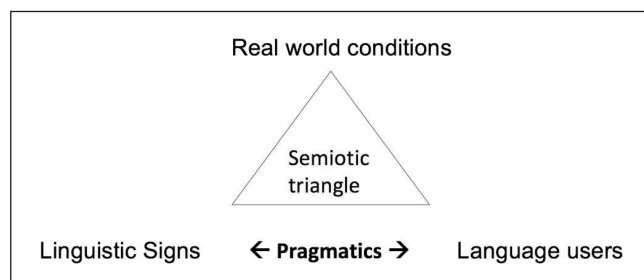


**FIGURE 1.** Semiotic triangle.

Whereas semantics is all about how linguistic forms relate to the world, pragmatics is all about how we learn to use linguistic forms by taking into account the language users—who is talking and what is their current context (Parikh, 2001). For example, if I am talking to you and we can see a dog, I could refer to him as 'the dog' but I could also say 'him' or use a pointing gesture. But if you can't see the dog then my saying 'him' without first saying anything else would be difficult for

you to understand. So, to choose between a noun (dog), a pronoun (him), and a pointing gesture, we need to know something about who we are talking to and in what context.

Context includes the physical context (what is around us), the discourse context (what has already been said) and also the cultural context (what is in common knowledge between people even if they haven't met before just by virtue of belonging to the same cultural community). Whenever two or more people are mutually aware of something in a given context, we can say that thing is in **common ground**. We use language to put things in common ground and good language users are very sensitive to what is or isn't already there. They are also sensitive to what the purpose of the conversation is—what linguists call the **Question Under Discussion**—and how our conversation is geared around resolving that question or moving on to a new one. That is, they can make their language relevant to what we are talking about. Becoming an expert language user requires practice in interaction and lack of access to conversation can cause many children who are deaf and hard of hearing (DHH) to struggle with some aspects of pragmatic development (Szarkowski & Toe, 2020). In what follows we will consider pragmatic developments that come with the discovery of prelinguistic communication, words, sentences, and supra-sentential structures, as well as nonliteral language. The focus will be on the developmental trajectory of typically hearing children learning a spoken language, although some signposts to research with DHH children learning spoken and/or signed languages will be given along the way. This article does not address debates about the best way to support pragmatic development in DHH children, regarding which far more high-quality evidence is needed.

## PRAGMATIC DEVELOPMENT DURING INFANCY

Right from birth, babies are tuned in to the people around them. They pick up on eye contact, on the characteristic way we talk to babies, and on any reactions to their movements. Communication is all about seeking a response and a sense of togetherness. Towards the end of the first year, babies start to use babble and gestures to direct other people's attention to things and events in the world. They become able to initiate and respond to joint attention, which is when two people are mutually aware that they are attending to the same thing. This is crucial because language works by moving the spotlight of joint attention over whatever it is we want to talk about (Matthews, 2020; Tomasello, 2003).

Before children even utter their first words, they are already performing a range of speech acts—be it commanding someone to do something (imperatives), stating something (declaratives), or asking questions (interrogatives) (Bates, 1976). They generally achieve this through babble and gesture, and by 11 months they tend to co-ordinate the use of both of these means with gaze to their interlocutor. We recently found that, for typically hearing 11- to 12-month-old infants, the more frequently they vocalize and look to their caregiver's face (so called gaze co-ordinated vocalizations) and the more their caregiver responds in a timely, accessible, and semantically contingent fashion, the more words they are likely to produce during the second year (Donnellan et al., 2019). We also saw that infant gestures, like showing and index finger-pointing, elicit responses and predict language development. Infants who are DHH with reduced access to a fluent language and communication model are at risk of producing these prelinguistic communicative acts at lower rates, in turn limiting the number of exchanges they can learn from (Kelly et al., 2020). We think this may occur because, while typically hearing parents with typically hearing infants often use nonlinguistic sounds (like gasps) in temporal synchrony with visible action in order to maintain joint attention with very young infants, this multimodal synchrony that supports learning is often missed by DHH infants whose parents have little intuitive deaf awareness. Deaf parents often intuitively use other strategies to achieve joint attention. An important question is how best to support these early stages of development for all DHH infants given very different family circumstances.

By their first birthdays, most typically hearing babies are on the cusp of using words to help make themselves understood. These are often first noticeable in well-practiced routine activities. Gradually, from these routines—and caregivers' responses to them—toddlers come to expect that such a word is used in such a context, that using it will have a reliable effect on the person they are speaking to, and that, as speakers and listeners, we are mutually aware of these effects—that is we

have a shared expectation that this is how language works. At this point, babies have grown into members of our language community. From here on in, learning language is all about figuring out how to use the different linguistic tools in our language toolbox. Each word performs a certain function and stands in contrast to other words that sometimes perform subtly different jobs. For example, the words *lion*, *tiger*, *cat*, *pet*, and *predator* are all related to each other but they mean different things and we have to carve out the meaning of each word by figuring out how they are conventionally used and how they contrast with other words (Clark, 2007).

Even when children can only use a few words, they already put them to good use. They spontaneously comment on whatever is new or changing in their current context, leaving things that remain constant unsaid. For example, if a plane flies by overhead, this changing element of the perceptual scene attracts attention and becomes something worth talking about. Given that other people in the room are also likely to have noticed the plane, they naturally find that it was something worth commenting on (Greenfield & Smith, 1976). Now that the topic of the plane is set, they might add something new in relation to it, for example, by commenting on how noisy it is. And this is how the topic-comment structure of language tends to work. We initiate a topic, then comment on it and build from there, adding comments until the conversation reaches a natural conclusion or we gradually switch topic (Bates, 1976). There comes a time when children want to comment on things that are not right in front of them and will not be immediately obvious to a partner on the basis of hearing just a word or two. When the topic cannot be presupposed on this basis, children need to first set it up linguistically before commenting. By the time children reach preschool, many of them are discovering the power of multiword speech to help them achieve this.

## PRAGMATIC DEVELOPMENT DURING THE PRESCHOOL YEARS

Around their second birthday (or the point at which they have about 200 words in their lexicon), many children start to combine words into more complex utterances. And over the preschool years they acquire the expressive power of human grammar. They can now express complex semantic relations like who is doing what to whom. And they can also express complex pragmatic relations like topic-comment relations that make it obvious how what we are saying contributes to the ongoing conversation or the Question Under Discussion. Complex expressions can even differentiate what children are intending to say from plausible alternative messages. For example, we might say 'I want the spotty dog' in contrast to 'the little dog' if there are multiple confusable referents. Without knowing it, what children are learning about at this

age is something called information structure (Lambrecht, 1994; Vallduví & Engdahl, 1996). This has two elements—information packing and information status.

Information packaging involves linking what is currently being said to our model of the world and the prior discourse—most importantly to the topic or the question under discussion. Basically, the topic is what the utterance is about. It anchors what is being said to the ongoing conversation. The comment or focus is what is uncertain—this is where new information is contributed. Information packaging is all about making the relations between what is under discussion and what is now being said clear. For example, if we ask a question ‘Who smiled?’, then someone might answer ‘*Mary* smiled’ or ‘*Mary* did’, with the emphasis on Mary. But if instead we ask, ‘What did Mary do?’ the reply might be ‘*Mary smiled*’ or ‘*she smiled*’ with the emphasis on smiled. That is, we can emphasize the part of the sentence that adds the new information and resolves the question. In English and other Germanic languages, we rely heavily on prosody—or the melody of language—to handle information packaging. Evidence from Dutch suggests it takes until into adolescence to master this (Chen, 2011). Information packaging also shows up in other ways like the order in which we say things with topics tending to come before comments. Special constructions are often used for this purpose, for example clefts like ‘It was Mary who smiled’.

Information status involves making sure the things we are referring to are clear. So, if we are talking about Mary for the first time, we need to make her accessible. If we both know Mary we can use her name. If not, I might describe her to you as ‘The girl over there with the long hair’. If we’re already talking about Mary then we might now refer to her as ‘she’. Basically, we need to choose a referring expression that makes whoever or whatever we are referring to accessible to the person we are talking to. Languages make different referring expressions available on an accessibility hierarchy (Ariel, 1988; Gundel et al., 1993) and a big job in learning to communicate effectively is knowing when to use which type of expression by taking into account what we have in common ground with other people. This is something we learn by trial and error, and experience of feedback and repair drives learning (Matthews et al., 2007; see work by Céline Hidalgo and colleagues for evidence with DHH children).

By the time children are reaching the end of preschool, they are typically good at understanding how people use different expressions informatively in context and predicting what will be said in a given setting (Morisseau et al., 2013). They can now make quite sophisticated inferences about what someone must have intended to mean given what they said. For example, if they see the following picture (Figure 2, replicated from Stiller et al., 2015) and you say ‘My friend has glasses’, they will

guess that you are talking about the middle character since if you’d meant the right hand one you’d have said ‘glasses and a hat’.

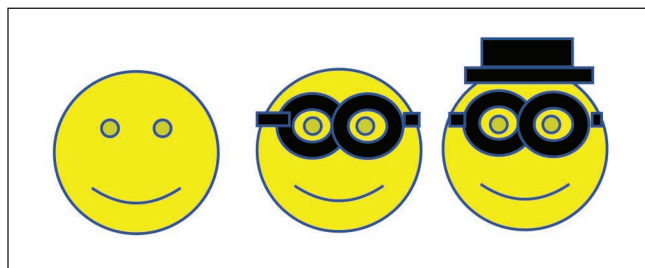


FIGURE 2. Reconstruction of Stiller et al. (2015) stimuli.

## PRAGMATIC DEVELOPMENT DURING THE PRIMARY SCHOOL YEARS

As children start school they continue to build on the skills they need to make themselves clear and to understand others. They become skilled not just at putting words together but at putting several sentences together to make a coherent conversation or narrative. When comprehending, they make even more complex inferences. With these skills they become increasingly able to talk about things removed in space and time, i.e. to understand and produce decontextualized language. Other accomplishments include the mastery of indirect speech acts (for example saying ‘I’ve lost my pencil sharpener’ to mean ‘Can I borrow yours?’) and presupposition (which involves understanding, for example, that ‘I’ve given up eating sweets’ presupposes I used to eat sweets). Finally, children master the use of nonliteral language so that by the time they start high school they are capable of being sarcastic in adult-like ways. Let us briefly consider these developments.

### Conversation

When having a conversation with someone else, children are increasingly capable of advancing the Question Under Discussion by using their turn to add something relevant with fairly good timing (Abbot-Smith et al., in prep). They learn not to dominate the conversation, to ask other people questions, and to take in their answers. They become able to make a variety of conversational moves, including asking for clarification if they are struggling to follow what is going on. For many DHH children, acquiring spoken language in conversation can be a challenge (Church et al., 2017; Paatsch & Toe, 2016).

### Narrative

During the primary school years children become able to relate a series of events that have happened in the past or in a fictitious world to another person using narrative (Aksu-Koç & Aktan-Erciyes, 2018). To do this they may choose to talk about things in a given order and to use cohesive devices (like *and*,

*then, or because*) to make it clear how the elements of the narrative connect to each other. If their narrative includes many different characters they will need to be introduced, maintained, and reintroduced at relevant points along the way so that they are always readily accessible for the audience. All children's skills for managing information structure are put to the test when producing narratives and when comprehending them, and practice with a supportive interlocutor helps (Carmioli et al., 2018; Carmioli et al., in prep).

### **Inferences**

Children make inferences both to make sense of words within a sentence and to make sense of stretches of sentences (Davies et al., 2020). So, if they hear 'Kate praised Jane because she had done well' they will infer that 'she' refers to Jane not Kate. Or if they hear an extract 'Jim got out the picnic supplies. The lemonade was icy cold' they assume that the lemonade was part of the picnic supplies. By making inferences, children integrate different elements of language and real-world knowledge to form a coherent mental model. Children need to do this all the time to understand spoken language and they also need to do this when reading. In fact, reading comprehension is all about creating an integrated mental model by combining information in a text and real-world knowledge given the reader's purpose.

### **Nonliteral Language**

Perhaps the most remarkable pragmatic development of all is children's growing ability to use language nonliterally. Children typically play around and joke with language from an early age. By the time they start primary school they are beginning to be able to use it to lie and to tell when others are doing so. While not always a welcome achievement, this is an important milestone and one that is often reached later by DHH children with reduced access to language. DHH children learning BSL from a fluent signed model are not delayed (Kelly et al., 2019). Children come to use metaphor to highlight attributes of something under discussion (for example, calling a teacher 'a rock'; Pouscoulous & Tomasello, 2020; Winner, 1988) and metonymy to make shortcuts in conversation (e.g., referring to someone as 'the beard'; Falkum et al., 2017; Papafragou, 1996). It takes years for these tropes to be mastered but perhaps the most complex of all is irony, particularly sarcasm. For example, by saying 'this is such great weather' when it rains on our picnic, a child has mastered a way of exploiting what is in common ground and using a tone of voice and facial expressions to humorously convey an attitude (Filippova, 2014; Wilson, 2020). This requires advanced mental state understanding and is often delayed in DHH children with reduced access to language and interaction (O'Reilly et al., 2014).

With all these advanced pragmatic developments, children are relying on substantial experience of interactions to anticipate what people will say and read their communicative intentions. They become persuasive and performative, caring and cutting, funny and fast. But not all children go about it in the same way. For a start, different cultures use language in different ways and children learn to become members of whatever cultural environments they're exposed to, with bilinguals adapting accordingly (e.g., Serratrice et al., 2004).

### **WHY DO SOME CHILDREN FIND PRAGMATIC ASPECTS OF LANGUAGE EASIER TO MASTER THAN OTHERS?**

Pragmatic development is not a one size fits all phenomenon. Children learn to talk in very different ways (Matthews et al., 2018) and in very different surroundings. For example, a child who has grown up in a large family might have had to learn to use language in a different way to an only child who experiences mostly adult conversation at home. These different experiences can lead to slightly different strengths. Similarly, some elements of pragmatic development, for example the way narratives are organized, vary slightly in different cultures around the world. So, an English-speaking child growing up in the UK might learn to value slightly different things in a narrative compared to a Spanish-speaking child growing up in Costa Rica. It is not that one way of doing things is better than the other—they're just different. Finally, children differ in what they bring to conversation, for example children on the autism spectrum differ in the way they approach social communication and this will interact with the expectations of their cultural group (Norbury & Sparks, 2013).

Many DHH children face challenges in pragmatic development that begin in infancy and often persist into adulthood, but that can also result in strengths. For families with little prior experience, it can be a tricky to support babies' communicative development if a parent is used to intuitively relying on sound to regulate interaction in a way that would often not be accessible. While there has been real progress in recent years both in hearing technologies and in recognizing the legitimacy of sign languages and bilingualism, support for families is patchy and many DHH babies have delays in their early communication that then extend to later pragmatic developments, such as taking part in conversation or understanding irony. We still have a lot to learn on this front and high-quality evidence about what works in supporting DHH children's pragmatic development is sorely lacking. To make progress, it can help to remember that what children are doing is learning a set of pragmatic skills. Children's differences show up not only in the moment of using those skills, they fundamentally affect how children acquire them in the first

place. That is, a child's attention to their environment, the way they update representations while talking, and their ability to draw on the set of linguistic tools they are learning will all shape what they take away from an interaction and what they do the next time they strike up a conversation. We can all play a part in supporting this developmental journey and there is considerable scope to support DHH children and their families from early infancy onwards (Szarkowski et al., 2020).

## HOW CAN WE SUPPORT PRAGMATIC DEVELOPMENT?

Whether consciously or not, parents, teachers, and other adults are often faced with the challenge of supporting pragmatic development. We face this challenge whenever we struggle to understand or make ourselves understood. While scientific research on how to support pragmatic development is in its early days, there are few things that are likely to help. The first is providing an opportunity for interaction. Whether that's making the head space to be available for play or conversation, or providing children with the opportunity to interact with peers, it's clear the main way we learn about communication is by doing it. So removing any barriers to quality, naturalistic, and enjoyable interaction is a great starting point. From infancy onwards, taking time to have mini conversations by tuning in to what has caught a baby or child's attention, communicating with them about it in an accessible way, responding to their attempts to communicate, and expanding on them all helps them to learn the tools of language.

From preschooler-age onwards, we can help children to understand other people's perspectives and the need to adapt to them in communication. If what they are saying is so ambiguous they are struggling to get their messages across, giving feedback can help both to highlight the potential for misunderstanding and to give a model of what could have been said to be clear. It's all about helping them to see what needs to happen for communication to work and providing the language tools to make that happen. From about the age of 3, children want to play with peers more and more and giving them an opportunity to negotiate interactions will help them to feel comfortable in the two social worlds of childhood—the one involving adults and the one just with other children.

From primary school onwards, supporting pragmatic development can also include a meta-linguistic approach—that is, explicitly talking about how we talk. Practice with listening skills and comprehension monitoring can help children appreciate how fallible our understanding can be and what strategies we can use to check we got the message. We can also talk about conversations or stories and how they hold together. And we can talk about what someone meant

when they used a sarcastic turn of phrase or a metaphor, or what they implied by saying 'I ate some of the biscuits' to mean they didn't eat them all.

Generally speaking, important ingredients for language learning include:

- **Knowledge of words and structures**—the tools for communication.
- **Real-world knowledge**—knowing about the domain we are talking about.
- **Understanding other people's minds**—grasping that communication requires aligning with people and taking into account their perspectives.

To use these ingredients you also need:

- **Cognitive resources**—for example, attention and memory.
- **Practice**—like all skill learning, becoming an effective communicator takes time.
- **Motivation**—some of us are chattier than others but we all need a quiet moment from time to time.

Some children will struggle with some of these components. If we can't directly support a component (for example, by helping with vocabulary or perspective taking) we can sometimes reduce demands—perhaps breaking instructions into smaller parts to reduce memory demands, although there is a risk here is of reducing access to the demanding conversational circumstances in which children most want to thrive (Szarkowski et al., 2020). Another option is to provide strategies, such as asking for clarification, or even phrases that often help in a conversation. Ultimately, some children are going to communicate in a slightly different way to others. If we raise awareness of this so that all children are open to differences, we can all share the work of communication and enjoy its benefits together.

## SUMMARY

Humans are an incredibly social species. Newborn babies come into the world seeking out interaction and quickly build on this experience to become effective communicators (Matthews, in prep). They discover the power of words and grammar as tools not just for combining ideas, but for sharing them with others in a manageable way. They become able to organize whole sequences of sentences and integrate them with knowledge of the context to create models in our minds—of reality or fantasy. They can use language to ask questions, to share information, or just to make us laugh. They can put things in a certain light and draw inferences about what other people must have meant by what they said. All of these skills take time to learn from practice doing what humans do best—taking time to share a moment with each other (Tomasello, 2019).

## ACKNOWLEDGEMENT

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## VIDEO RESOURCES

The current overview as a YouTube video series:  
[www.youtube.com/playlist?list=PLxU3mZKOM1zWTkaPKwKuF-c9g5Zlt2o6BS](https://www.youtube.com/playlist?list=PLxU3mZKOM1zWTkaPKwKuF-c9g5Zlt2o6BS)

## VIDEO SERIES FOR PARENTS WITH A DHH INFANT:

<https://www.youtube.com/playlist?list=PLiKwROOiu2Dm8f-ph0F-prztKIEhrNjHdG>

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# Literacy in Children with Hearing Loss: Understanding Acquisition to Improve Intervention

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## ABSTRACT

*The ELLA Study is a longitudinal investigation of language and literacy acquisition in children with hearing loss. The total sample includes 100 children with hearing loss and 60 children with typical hearing. Findings to date have shown that children with hearing loss exhibit delays across many early language and literacy skills relative to their peers with typical hearing. Additionally, children's engagement with books and entry in early intervention by 6 months of age are associated with higher language and emergent literacy outcomes.*

Literacy achievement continues to be a primary concern during the school-age years for children with hearing loss, despite advances in amplification technology and increased understanding of the science of reading. The growth rate of reading skills for children with hearing loss, as a group, is even slower than the growth rate for children with typical hearing and learning disabilities (Wei et al., 2011). Median reading outcomes for children with hearing loss plateau at about a fourth grade reading level (Qi & Mitchell, 2012); however, there is wide individual variation in literacy skills within the group of children with hearing loss who use spoken language (Werfel & Hendricks, 2016). There is a critical need, therefore, to understand underlying skills that contribute to low literacy outcomes for children with hearing loss. Our focus has been on oral language and code-based emergent literacy skills.

It is widely accepted that reading comprehension is the product of decoding/word recognition and language comprehension (i.e., Simple View of Reading; Gough & Tunmer, 1986; Kim, 2017). Importantly, word recognition must be automatic and decoding must be fluent. For example, strong readers immediately recognize a large number of written words without sounding them out (i.e., automatic word recognition) and are skilled at quickly decoding unfamiliar words. Decoding and word recognition rely on the interweaving of phonological and orthographic skills, including phonological awareness and alphabet knowledge. Language comprehension relies on the interweaving of multiple language skills, including vocabulary, morphosyntax, and complex syntax (Scarborough, 2001).

Children with hearing loss, including those who use spoken language, have documented deficits across both decoding/word recognition and reading comprehension. Camarata and colleagues (2018) reported that approximately one-third of children with mild to moderate hearing loss exhibited reading

impairments. Geers and Hayes (2011) reported that only 30 percent of adolescents who use cochlear implants performed within the average range on a measure of decoding, while 66 percent scored within the average range on a measure of reading comprehension. Within children who are hard of hearing, those with more severe degrees of hearing loss have lower reading outcomes (Tomblin et al., 2020).

## THE ELLA STUDY

The Early Language and Literacy Acquisition in Children with Hearing Loss (ELLA) Study is a longitudinal investigation of language and literacy acquisition in children with hearing loss who use amplification and spoken language. The study began in 2015; the initial phase included a sample of approximately 30 preschool children with hearing loss and 30 preschool children with typical hearing. In 2018 we expanded the study to include a total of 100 children with hearing loss and 60 children with typical hearing. The total sample includes 50 children who use hearing aids and 50 children who use cochlear implants.

Our aims in the ELLA Study are three-fold. Our first aim is to describe developmental trajectories of children with hearing loss in oral language and emergent literacy skills across the preschool years and literacy during the elementary school years, and to compare those trajectories to those of children with typical hearing. Second, we aim to identify preschool predictors of school-age literacy difficulties for children with hearing loss. Our third aim is to identify underlying mechanisms of emergent literacy difficulties for children with hearing loss, with a specific focus on lexical-semantic knowledge. The majority of our work to date has addressed the first aim, and work to address the second and third aims is in progress.

The initial phase of the ELLA Study in 2015 was motivated by multiple studies we had previously conducted. First, Lund et al.

(2015) reported that children with hearing loss performed lower than children with typical hearing across measures of vocabulary and phonological awareness. Second, Werfel et al. (2015) reported that children with hearing loss performed lower than children with typical hearing on conceptual print knowledge, but not alphabet knowledge. Finally, Werfel and Hendricks (2014) found that children with hearing loss did not demonstrate deficits on phonological recoding or rapid naming, and that patterns of contribution across phonological processing skills to spelling differed across school-age children with hearing loss and school-age children with typical hearing. Taken together, these early findings suggested that even by preschool, children with hearing loss exhibited deficits across many areas of early literacy, and that early literacy skills may impact literacy differently for this population.

The findings from the initial phase of the ELLA Study have confirmed many of our hypotheses based on this preliminary work. Overall, our findings have suggested widespread group-level deficits across oral language and emergent literacy for children with hearing loss, although individual performance has wide variation and these deficits are not always detected using norm-referenced measures. Additionally, we have reported evidence of multiple predictors of preschool language and emergent literacy skills.

## ORAL LANGUAGE FINDINGS

First, Werfel (2017) reported that children with hearing loss performed lower than their same-age peers with typical hearing on measures of vocabulary and morphosyntax at age 4, and these deficits remained six months later. Werfel and colleagues (under review) reported that children with hearing loss made similar growth in vocabulary across preschool as children with typical hearing; however, this growth was not sufficient to close the gap to performance similar to same-age peers with typical hearing at school entry. For morphosyntax, children with hearing loss made substantial gains over the preschool years; however, performance was still significantly below their same-age peers with typical hearing at school entry. Together, the findings from these studies suggest that children with hearing loss often begin the preschool years with oral language skills lower than their same-age peers with typical hearing and that these deficits remain two years later at the age of school entry.

The ELLA Study findings to date have also explored the use of language sample analysis for children with hearing loss. First, in Werfel and Douglas (2017), we reported that children with hearing loss who scored within 1.5 standard deviations of the mean on a norm-referenced language measure, and thus who would not qualify for language services in many U.S. schools, nonetheless performed substantially below their

peers with typical hearing on production of morphosyntax during naturalistic language samples. These production deficits spanned tense (e.g., regular past-tense marking) and non-tense marking (e.g., regular plural) morphemes. Werfel (2018) extended this language-sample based morphosyntax work to also include children with hearing loss who had norm-referenced language scores below the average range and reported again that they performed below their peers with typical hearing on a variety of tense and non-tense marking morphemes. Additionally, this work showed that morphosyntax weaknesses for children with hearing loss are a result of both perceptual- and linguistic-related weaknesses. Finally, Werfel et al. (2021) reported that children with hearing loss during the 4-year-old year have deficits in production of complex syntactic structures in naturalistic language samples. Overall, children with hearing loss had lower complex syntax density than children with typical hearing; that is, children with hearing loss used fewer complex syntax structure per utterance. Additionally, we identified several types of complex syntax that children with hearing loss produced less or less accurately than children with typical hearing, including coordinated clauses, subordinate clauses, simple infinitives, subject relative clauses, and full propositional complements.

## CODE-BASED EMERGENT LITERACY FINDINGS

Werfel (2017) reported that children with hearing loss perform lower than peers with typical hearing on measures of phonological memory and conceptual print knowledge at age 4. By age 4 1/2, deficits in phonological awareness had also emerged. No differences between groups were detected for alphabet knowledge or phonological recoding. Preliminary findings from the preschool phase of the study confirm these findings in children with hearing loss ages 4 through 6. Findings for phonological awareness, phonological memory, and conceptual print knowledge paralleled those seen for vocabulary, such that children with hearing loss begin the preschool years behind peers with typical hearing, make similar growth over the preschool years, and remain behind at school entry (Werfel et al., in preparation). For phonological recoding and alphabet knowledge, similar to Werfel (2017), no deficits for children with hearing loss were detected over the preschool years.

We have also evaluated phonological awareness and conceptual print knowledge in more depth for children with hearing loss. Specific to phonological awareness, we completed an experimental task that contrasted children's performance across four phonological awareness skills: initial sound matching, initial blend matching, rhyme matching, and final blend matching. Our preliminary findings suggested that children with typical hearing performed better on the two skills in which the unit of analysis occurred at the beginning of the syllable (initial sound

and initial blend matching), whereas children with hearing loss performed better on the two skills in which the unit of analysis was a single phoneme (initial sound and final sound matching). These findings suggest that performance on phonological awareness tasks may be differentially affected by phonological memory for children with hearing loss and children with typical hearing. That is, children with hearing loss appear to be more susceptible to unit length, and children with typical hearing are more susceptible to syllable position constraints. Specific to conceptual print knowledge, we have reported that children with hearing loss perform more poorly than children with typical hearing on test items that contain quantity or temporal/spatial conceptual vocabulary words, such as *more* or *first*, than items that do not contain conceptual vocabulary (Lund et al., 2020).

### PREDICTORS OF PRESCHOOL LANGUAGE AND EMERGENT LITERACY

Finally, we have reported on three predictors of preschool language and emergent literacy: home literacy environment, geographic location, and adherence to the Early Hearing Detection and Intervention guidelines. Reynolds and Werfel (2020) reported that parents of children with hearing loss report reading to their children similar amounts as parents of children with typical hearing; however, children with hearing loss had lower engagement during book reading sessions. This finding is important because children's engagement during book reading was related to their oral language and emergent literacy skills. We concluded that early intervention should focus on increasing children's engagement during book reading. Additionally, Lund and colleagues (under review) reported that only alphabet knowledge skills of children with hearing loss were affected by geographic location of the family (i.e., rural, suburban, urban). This finding suggests that despite barriers in access to healthcare that are known to be experienced by families who live in rural locations, these barriers do not appear to affect language acquisition during preschool for children with hearing loss. Finally, Grey and colleagues (2021) reported that entering early intervention by 6 months of age was an important indicator of later language acquisition. Therefore, ensuring that children with hearing loss are enrolled in early intervention by 6 months of age should be a priority focus during the identification process.

### NEXT STEPS

The next steps of the ELLA study include analysis of preschool skills' predictive value for elementary school literacy skills, with a primary goal of identifying early indicators that children with hearing loss may need more intensive or a different kind of early intervention. We are continuing to follow our cohort throughout elementary school to describe developmental trajectories of language, reading, and writing. Additionally, we will evaluate the

lexical-semantic underpinnings of language and literacy difficulties for children with hearing loss. Long term, we aim to continue to follow our cohort through early adulthood to evaluate long-term effects of preschool language and emergent literacy for children with hearing loss.

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# Benefits to Patients from Binaural Hearing: Spatial Perception and Cognitive Load

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## ABSTRACT

*Binaural hearing is critical for everyday communication. In the past two decades there has been a major shift towards providing cochlear implants (CIs) in both ears, recognizing that patients can potentially benefit from having the ability to localize sound and hear speech in noise. However, CIs were not designed as coordinated devices that can easily capture binaural cues. The Binaural Hearing and Speech Lab at the University of Wisconsin-Madison focuses on three important areas of study: sound localization, hearing speech in noise, and listening effort. This paper provides an overview of how our lab is assessing and working towards true binaural hearing for CI users.*

I had the chance to meet a friend at a restaurant in the middle of a busy downtown area. I had not been to this place before and was navigating my way around busy streets, paying attention to oncoming traffic, sirens in the background, and a group of school children excitedly maneuvering their way to a museum. My auditory system, and in particular my spatial hearing abilities, were on high alert as my brain was absorbing and processing multiple sound sources arriving from different locations and deciding where to draw my attention. I was able to safely cross the busy street and navigate my way to the restaurant, which was bustling with people and filled with lively conversations and music playing in the background. My first goal was to find my friend and look for quiet corner where we could sit down and catch up. My friend, who has a hearing loss in the right ear, asked to sit with her left ear near the wall, so that the noise from the restaurant would be less disruptive. Having no hearing loss, I was able to use information arriving at both of my ears to determine where different sounds were located in the room, and to direct my attention to important sounds in the room such as my friend's voice and the lovely music in the background.

How is it that having access to sound in both ears provides such advantages and benefits? Let's turn our attention to the complex magic of the binaural hearing system. Binaural hearing results from integration of sounds arriving at the two ears. Because the head is round and the two ears are positioned on either side of the head, when a sound arrives from a location in space (other than directly in front), the sound will arrive first at the near ear and subsequently at the far ear, causing differences in time known as inter-aural time differences (ITDs). The sound will also have greater intensity in the near ear than the far ear, causing differences known as inter-aural level differences (ILDs). The brain has exquisite mechanisms that act like an online

computer to analyze this binaural information and tell us where the sounds are located. In addition, when the brain compares information across the two ears, we are better able to hear speech in noisy environments. Binaural hearing is therefore critical for everyday communication, including in school environments and crowded social situations.

The topic of binaural hearing is particularly relevant to aiding people with hearing loss. During the latter part of the 20th century, it became clear that people who are eligible for hearing aids in both ears should indeed be fitted with bilateral hearing aids, thus audiological best practices embraced a shift towards optimizing binaural hearing abilities. Patients with limited benefits from hearing aids are candidates for intervention with cochlear implants (CIs); in fact, in the past two decades there has been a major shift towards providing CIs in both ears, recognizing that patients can potentially benefit from having the ability to localize sound and hear speech in noise. However, as a field we run into an important limitation: CIs were not designed as binaural devices that can easily capture binaural cues. In fact, they are clinically fitted separately on each ear without hard-wired or wireless inter-implant connection. From a historical context, that can be easily understood because CIs were originally designed to capture information that is important for understanding speech, so that infants and children who are born deaf can acquire language. In addition, CIs were intended to restore as much hearing as possible to children and adults who lost their acoustic hearing. Another unique group of patients who are now beginning to regain access to bilateral hearing are those with hearing loss in one ear (single-sided deafness, SSD), who are eligible for a CI in the deaf ear (SSD-CI). For these individuals, the auditory brain has the unique challenge of integrating two very different sounds: acoustic and electric hearing.

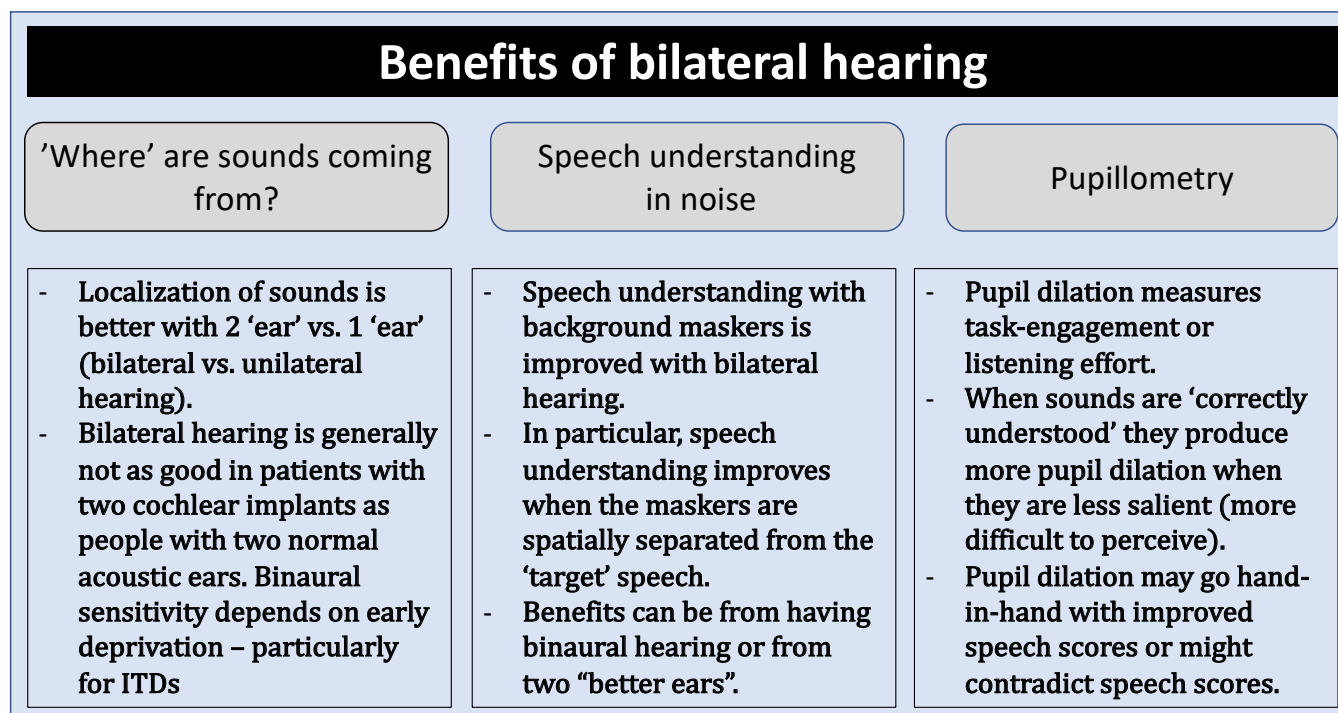


**FIGURE 1.** Summary of the benefits that can potentially be gained from having access to sound in both ears.

You might be asking—how do we study the benefits of bilateral hearing (two CIs or one CI + acoustic hearing)? The Binaural Hearing and Speech Lab at the University of Wisconsin-Madison focuses on three important areas of study: sound localization, hearing speech in noise, and listening effort. The benefits are summarized in the diagram in Figure 1.

Sound localization is assessed by asking participants to sit in front of loudspeakers, set up in a room along the horizontal space, and to tell us where a sound is perceived to be coming from. We measure the average errors made when only one ear is used compared to when both ears are used. People with bilateral CIs have significantly smaller errors (about 20-30 degrees) when using both CIs compared to one CI alone (50 degrees or more) (see Litovsky et al., 2009). This is also the case for children who receive bilateral implants (Grieco-Calub & Litovsky, 2010). In fact, for children we also see that experience with both CIs leads to improvement in localization over a 2- to 4-year period after the second CI is activated (Zheng et al., 2015). In adults with SSD-CI we have observed that turning on the CI, compared with only listening with the typical-acoustic ear, improves localization accuracy in a similar way to the bilateral CI findings (Litovsky et al., 2018). When we test the ability to hear speech in noise, many studies from our lab and other labs have shown that improvement from bilateral CIs can be significant; listeners can hear speech at quieter levels, and

when the noise and the 'target' speech that listeners attend to are placed in different locations, there is a 'release from masking'—it becomes easier to understand the speech when its location is not the same as the noise (Litovsky et al., 2006; Loizou et al., 2009; Misurelli & Litovsky, 2015).

While there are benefits from having sound in both ears, patients do not usually perform as well as listeners with typical hearing. Examples of localization data from adults and children are shown in Figures 2 and 3, respectively. As can be seen, while localization errors with bilateral CIs are less than 30 degrees, they are notably worse than errors seen in typically hearing adult and child listeners.

Also very helpful for localization is the position of the microphones (Jones et al., 2016). As can be seen in Figure 4, we studied sound localization in adults with bilateral CIs, comparing location of the microphones in the ears (ITE), behind the ears (BTE), or on the shoulders (SHD). Figure 4 (left panel) shows that a very important binaural cue for localization, the range over which ILDs are available, is largest for ITE, then BTE, and smallest for SHL. This was consistent with localization accuracy, which was best for ITE, followed by BTE, and finally SHD (see Figure 4, right panel). These data suggest that, if clinically feasible, microphones should not be placed on the shoulders (as sometimes happens with young children), ideally should be inside the ear canal, and behind the ear is the middle option.

## Example of sound Localization in adults

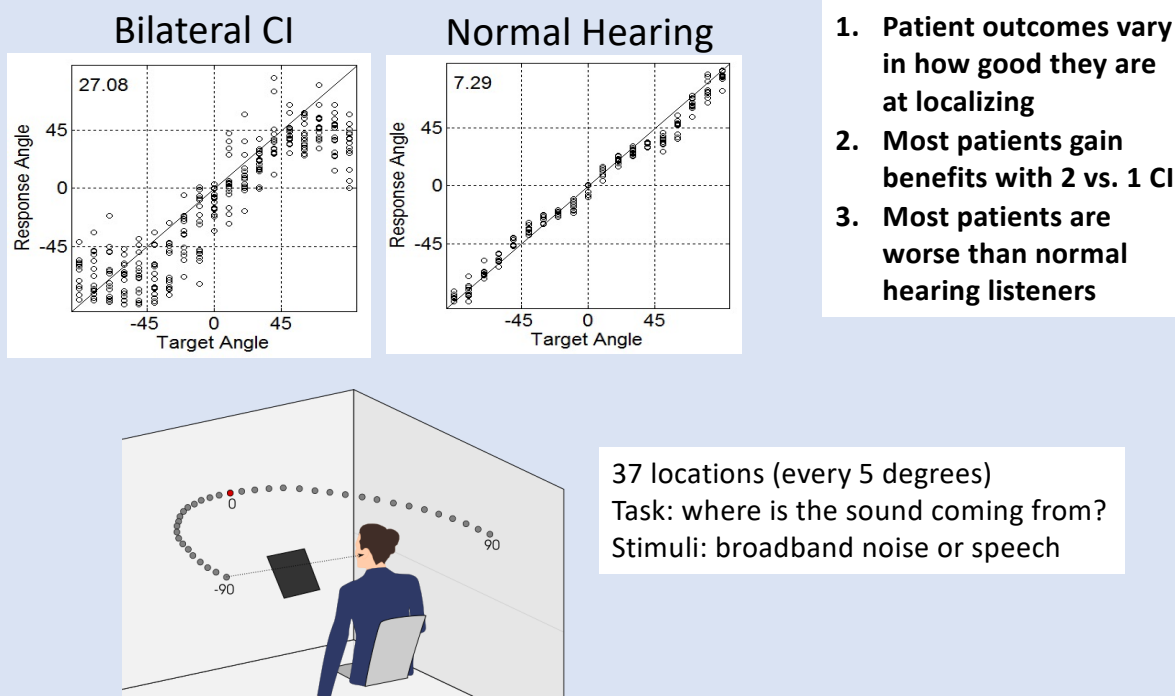


**FIGURE 2.** Examples of sound localization data from one adult with bilateral CIs and one adult with typical hearing. Each graph shows the response as a function of the locations, and the inset in each figure shows the average error (27.08 degrees and 7.29 degrees, for CI and typical hearing, respectively). The bottom of the figure shows a rendition of what the localization 'room' looks like for these tests (artwork courtesy of Michaela Warnecke, PhD).

## Example of sound Localization in children

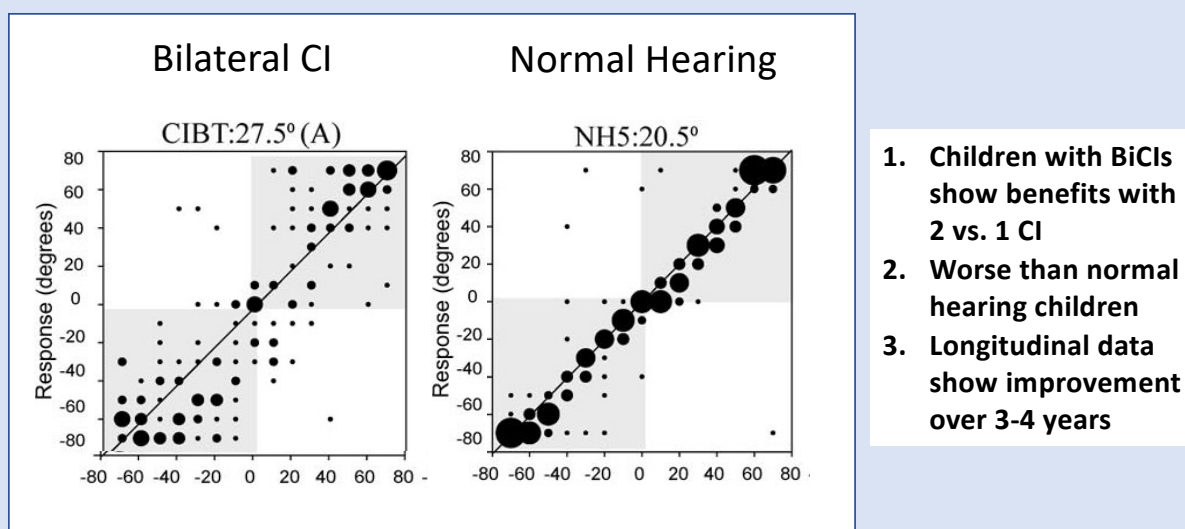


**FIGURE 3.** Examples of sound localization data from one child with bilateral CIs and one child with typical hearing. Each graph shows the response as a function of the locations, and the inset in each figure shows the average error (27.5 degrees and 20.5 degrees, for CI and typical hearing, respectively). These data are replotted with permission from Grieco-Calub and Litovsky (2010).

## Location of microphones

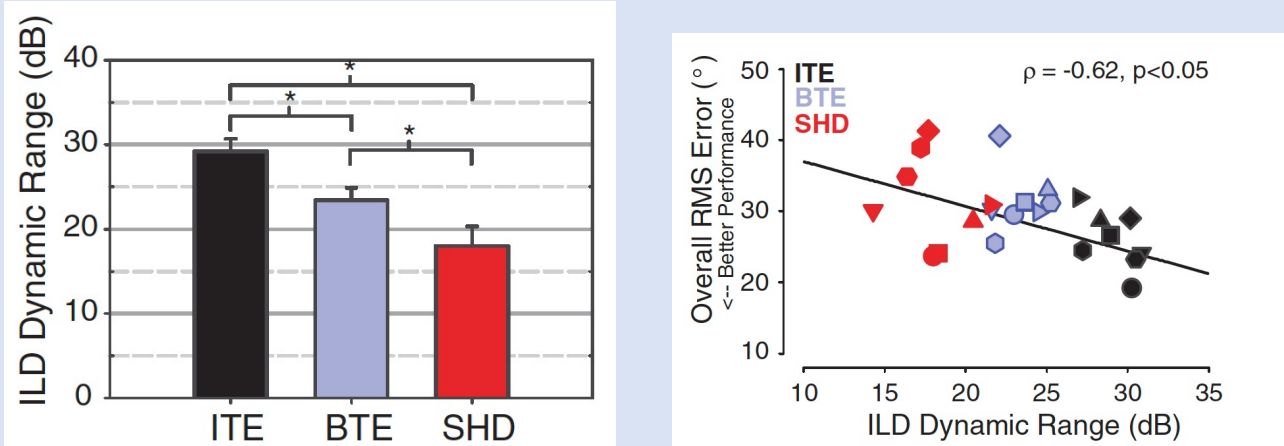


**FIGURE 4.** Sound localization in adults was measured with bilateral CIs, comparing location of the microphones in the ears (ITE), behind the ears (BTE), or on the shoulders (SHD). Left panel shows the range over which ILDs are available for each condition (averaged all patients who participated in the study). Right panel shows results from localization testing (errors on Y axis) as a function of the ILD dynamic range from the right panel. These data are replotted with permission from Jones et al., 2016.

While the location of microphones is important, CI listeners still perform worse than listeners with typical hearing. There are various reasons for these differences, such as the fact that two CIs are not ‘linked’, which means that they each send signals to the brain at their own pace without ensuring that the timing of the signals are coordinated or synchronized. Because binaural hearing in the typical acoustic system depends on the brain getting coordinated signals from the two ears, there is a clear need for research on how to ‘restore’ coordinated information to the CIs of bilateral CI users. Much of the research in our lab over the past 15 years has focused on using nonclinical research processors to study how we can best reintroduce true binaural hearing to CI users. We have discovered that when specific electrodes in the right and left cochleae are ‘paired up’ according to similar perception of pitch, we see an excellent ability to hear the binaural cues (ITDs and ILDs) (Litovsky et al., 2010). Figure 5 shows two drawings of electrode arrays from the CIs in the right and left ears. If the CI on the right ear has information sent to electrode #12, the electrode on the left that sounds most similar may not be the same number and could be closer to the top (apex) or bottom (base) of the cochlea. The important part of matching pitch is that it leads to better outcomes in binaural hearing and separation of speech in noise (Goupell et al., 2013; Goupell et al., 2018; Kan et al., 2015; Litovsky et al., 2012).

A very important part of this work is the finding related to auditory plasticity: adults who lost their hearing early in life or

children who were born with congenital deafness struggle greatly with hearing out ITDs, but they can hear small differences in ILDs. In contrast, all patients, including adults who were deaf early in life and all children, can hear out the ILDs. That means that the brain can ‘remember’ how to process ILDs and that the circuits in the brainstem that compute ILDs are not too vulnerable to auditory deprivation. However, the brain loses its ability to use ITDs without hearing those sounds. We know that ITDs are extremely important and helpful for everyday localization and for separating speech from noise. Therefore, we are highly motivated to continue looking for ways to engineer bilateral CIs that do a good job of enabling patients to use ITDs (Bennett & Litovsky, 2020; Kan & Litovsky, 2014; Thakkar et al., 2020).

Finally, consider whether hearing with both ears is ‘easier’ and demands less ‘effort’ than hearing with one ear. Many patients report that they are less fatigued and have to work less to be able to communicate in the real world when they are ‘wearing both ears’ than when they only wear one ear. Our earlier work sought out answers to this question using questionnaires where patients were asked to rate their use of one versus two CIs. These days we have been using objective measures to study this important question. One objective tool is the size of the pupil, which changes when listeners ‘engage’ or ‘try hard’ to hear. We are now exploring ways to assess if adding a second ear will help many patients (Winn & Litovsky, 2015; Winn et al., 2018). Our initial findings are promising, showing that many patients have decreased pupil dilation in addition to better speech perception

## Interaural pitch matching & loudness balancing

- *Insertion depth of electrodes*

→ Pitch-matching results in:

- (1) *Greater number of fused/coherent auditory images*
- (2) *Better localized in the head*
- (3) *Better right-left discrimination*
- (4) *Better speech intelligibility*

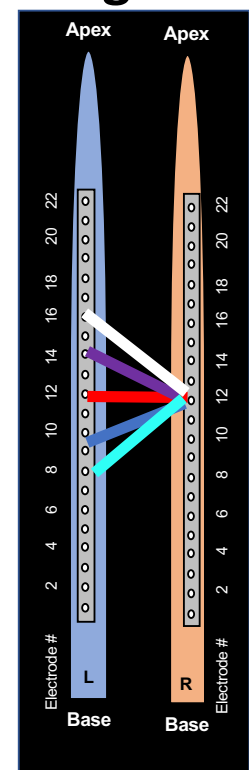
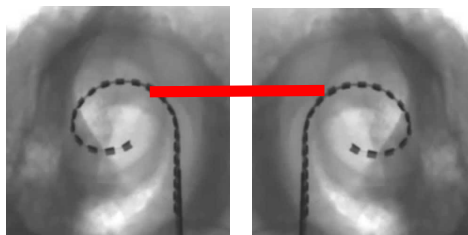


**FIGURE 5.** Two drawings of electrode arrays from the CIs in the right and left ears, with electrodes ranging from the top (apex) or bottom (base) of the cochlea. This diagram is intended to show where the stimulation to the CIs in each ear can be sent, in order to test if the sounds in the two ears are heard as having the same pitch.

with two ears versus one ear. However, not all patients show this effect, suggesting that sometimes putting together information from the ears is helpful (better speech perception) but costly (takes more effort).

In conclusion, binaural hearing is one of the most important aspects of the auditory system, because it impacts nearly every aspect of communication, learning, and safety in naturalistic environments. For a deeper background on all aspects of binaural hearing please refer to a recent book by Litovsky and colleagues (Litovsky et al., 2021). Patients who are deaf and fitted with two CIs, or a CI in the deaf ear opposite an ear that has acoustic hearing, can potentially benefit from having access to sound in both ears. Improvements are seen in sound localization, hearing speech in noise, and reports of reduced effort. However, CI users are generally still worse on these tasks than listeners with typical hearing.

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