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Linking Language and Cognition in Infancy

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Abstract

Human language, a signature of our species, derives its power from its links to human cognition. For centuries, scholars have been captivated by this link between language and cognition. In this article, we shift this focus. Adopting a developmental lens, we review recent evidence that sheds light on the origin and developmental unfolding of the link between language and cognition in the first year of life. This evidence, which reveals the joint contributions of infants' innate capacities and their sensitivity to experience, highlights how a precocious link between language and cognition advances infants beyond their initial perceptual and conceptual capacities. The evidence also identifies the conceptual advantages this link brings to human infants. By tracing the emergence of a language–cognition link in infancy, this article reveals a dynamic developmental cascade in infants' first year, with each developmental advance providing a foundation for subsequent advances.

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INTRODUCTION

Language is a hallmark of our species and our most powerful cultural and cognitive tool. The power of language derives not from the exquisite detail of its signals or the precision of its grammatical rules but from its intricate and inextricable link to human cognition. This link, unparalleled elsewhere in the animal kingdom, serves as the conduit through which we share with others the contents of our minds. It enables us to move beyond the exigencies of the here and now, to represent the past and the future, to build upon one another's knowledge and beliefs, and to consider different perspectives on the same phenomena. Through human language, we can essentially hijack one another's minds, working collectively to invent history and time, to promote religious beliefs and scientific theories, and to create literature and art.

George Miller (1990, p. 12), a father of the cognitive revolution in psychology, described this uniquely human link eloquently:

> Human language is the happy result of bringing together two systems that all higher organisms must have: a representational system and a communication system . . . . A representational system is necessary if an organism is going to move around purposefully in its environment; a communication system is necessary if an organism is going to interact with others of its own kind. Presumably, some of the historical disagreements over the importance of language for our understanding of human cognition arose because different protagonists identified language with different parts of this combination. It is certainly true that human beings are not the only animals capable of a complex representational intelligence, nor are they the only animals that communicate. But human beings do seem to be the only animals in which a single system serves both of these functions.

Questions concerning this relationship between human language and cognition have long captivated attention in all of the fields currently within the cognitive sciences (Fodor 1975, Gleitman & Papafragou 2005, Whorf 1956). Decades, if not centuries, of lively debate have illuminated several issues that lie at the intersection of human language and cognition, but, until recently, a more fundamental question has been left unaddressed: How do infants begin to forge a link between language and cognition in the first place? And what advantages, if any, do such links afford the developing infant mind?

In this article, our goal is to shed light on the developmental origins of this uniquely human link and to trace how it unfolds in infancy. Focusing primarily (but not exclusively) on the first year of life, we peel back the layers to reveal the foundation of this language–cognition interface. Shifting the focus to infants also shifts the questions under investigation. The question is no longer whether language and cognition are linked; instead, the questions are how this link begins, what initial capacities (if any) support infants as they first forge this link, how these capacities are then sculpted by the forces of maturation and experience, and how this precocious link advances infants' acquisition of knowledge.

Three Recurring Themes

Three interrelated themes central to the developmental sciences are woven together throughout this review (**Figure 1**). These themes, built on an assumption that human infants are endowed with an innate capacity to acquire human language (Chomsky 1986, Gleitman 1990, Pinker 1994), guide current investigations into how a language–cognition link unfolds and how this link fuels infants' acquisition of core cognitive capacities. The first theme concerns the joint contributions of maturation and experience. We examine how these twin engines of development guide infants to establish increasingly precise links between language and cognition. The second theme is the idea that human language and cognitive development are best characterized as a series of cascading effects that unfold over developmental time, with each point along the developmental continuum

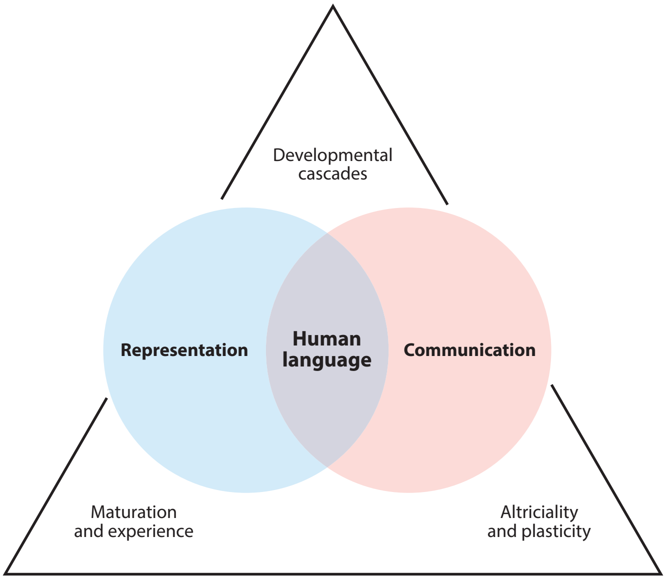

Figure 1

Human language occupies the intersection of our systems for representation and communication. Interactions between nature and nurture—reflected in the sculpting forces of maturation and experience and in the synergy between altriciality and plasticity—provide our foundation for language. Developmental cascades, in turn, characterize our acquisition of language.

setting constraints upon the next (Werker & Hensch 2015). The third theme, articulated below, highlights the importance of two other signatures of our species—our altricial status at birth and our exceptional developmental plasticity.

Human infants are altricial at birth, neurally and behaviorally immature even in comparison to our closest evolutionary relatives. For example, the human infant's brain at birth is less than 30% the size of an adult's, a ratio that is substantially lower than that observed in other primate species (DeSilva & Lesnik 2006). Moreover, infants of other species are endowed at birth with the behavioral tools that permit them to maintain proximity with their caregivers (e.g., an ability to cling to their caregivers or to locomote alongside them), but human infants have no such behavioral endowment. Notice that this altricial status brings with it a developmental imperative: It falls to human caregivers to maintain close contact with their infants and to do so for an extraordinarily protracted period. Human infants' exceptionally long period of dependency, paired with their innate cognitive and linguistic capacities (Carey 2009, Chomsky 1986, Spelke & Kinzler 2007) and their responsiveness to experience (Kuzawa & Bragg 2012, Werker & Hensch 2015), is "advantageous for a species whose major specialization is its capacity for learning and whose basic invention is culture" (Gleitman et al. 2011, p. 588). And, we add, these foundations of human development are also advantageous for a species whose signature is the link between language and cognition.

The Advantages of Adopting a Developmental Lens

Approaching the relationship between language and cognition using a developmental lens is especially compelling. Although an infant from a remote village in the Chaco rain forest and an infant from an urban Chicago neighborhood will each grow up amid objects and events that the other has never seen, immersed in daily practices that the other has not witnessed, and listening to language that the other cannot understand, there are strong convergences in their acquisition of fundamental conceptual and linguistic capacities (Schieffelin & Ochs 1986, Waxman & Lidz 2006). Within their first year, infants across the world's communities begin to acquire language. Also within their first year, infants establish categories of objects and events (e.g., DOG, BOTTLE; RUN, SLEEP) that capture commonalities among distinct individual objects or events. These early categories serve as a basis for learning and guide infants' expectations about objects and events that they have not yet witnessed. These categories, rudimentary at first, also develop in alignment with a small set of abstract concepts, including concepts as fundamental to human thought as objects, number, space, causation, and agency (Baillargeon et al. 2016, Carey 2009, Spelke 2017).

Importantly, these early linguistic and conceptual advances do not proceed independently. Instead, infant language and conceptual development are powerfully and implicitly linked (for reviews, see Ferguson & Waxman 2016a, Swingley 2012).

When we adopt a developmental lens, it becomes clear that this link unfolds dynamically, beginning in the first months of life. Uncovering this dynamic process—as well as the factors that drive it—has major implications for understanding the ontogenetic and phylogenetic origins of human language and cognition.

LANGUAGE EXERTS A HIDDEN POWER: THE EFFECTS OF LANGUAGE IN EARLY CONCEPTUAL DEVELOPMENT

In the words of ancient Greek poet Alcaeus, "Language exerts a hidden power, like the moon on the tides." Although he almost certainly could not have known it at the time, this is an especially apt description of the effects of language on infant cognition in the first year of life. Three lines of recent developmental work, each with its own theoretical framework, have shed new light on the ways in which language exerts this influence in infancy. These lines of research include investigations of the link between words and categories, core knowledge, and natural pedagogy.

Words as Invitations to Form Categories

Most research investigating the early development of a link between language and cognition in infants and young children has focused on word learning. This focus makes sense because word learning is an achievement that stands at the crossroads between linguistic and conceptual development. After all, to learn the meaning of a word, learners must identify a portion of the ongoing stream of speech (a problem for a communication system to solve), identify a referent for that word (a problem for a representational system to solve), and establish a mapping between the word and its referent. Moreover, the early word learning research focused primarily on object categories. This focus is apt because categories are fundamental building blocks of cognition. They exert far-reaching influence on virtually all aspects of learning and cognition across species and across development: When we identify two objects as members of the same category, we establish their equivalence at a certain level of representation, permitting us to identify new members of the category and to make inferences about nonobvious properties from one member of the category to another. This has tremendous consequences for subsequent learning; for example, by establishing a category DOG, we can learn from just one encounter with a single dog to avoid all dogs that bare their teeth (even ones we have not yet seen) instead of painfully and repeatedly requiring first-hand evidence from each individual dog that happens to bare its teeth. Object categories also support memory and reasoning, guiding our predictions about the likely behaviors and properties of objects—even objects we have yet to encounter and properties (e.g., an organism's DNA) that we have never observed (Gelman 2004, Medin & Ortony 1989, Waxman & Gelman 2009).

Roger Brown (1958), the father of the modern study of child language and a contemporary of George Miller, famously argued that words are invitations to form categories. When he articulated this point of view, Brown had preschool-aged children in mind. However, more recent developmental evidence reveals that, even before infants begin to speak, words invite them to form categories. The evidence for this claim comes from a robust behavioral paradigm, elegant in its simplicity. It is essentially an object categorization task with two phases. During the familiarization phase, infants view a series of discriminably different objects (e.g., dog, horse, duck) from a given object category (e.g., animal). Next, during the test phase, infants view two new objects—one a member of the now-familiar category (e.g., a cat) and the other a member of an entirely different category (e.g., an apple). The logic of this paradigm is straightforward: If infants detect the category-based commonalities among the familiarization objects, then they should distinguish the novel test image from the familiar; if they fail to detect these commonalities, then they should perform at chance levels (Aslin 2007, Colombo 2002, Golinkoff et al. 1987). Because this paradigm permits researchers to hold constant the objects infants view while systematically manipulating the amount and kind of auditory information that infants hear, designs like this have shed light not only on whether infants can form object categories, but also on how their capacity to do so is shaped by language.

The evidence reveals that, by 12 months of age, even before they produce more than a few words on their own, infants have established a principled link between object naming and object categorization. If each in a series of familiarization objects is introduced in conjunction with the same novel word embedded in a naming phrase (e.g., "Look at the blick!"), infants successfully form an object category, exhibiting a reliable preference for the novel test object (e.g., the apple rather than the cat). However, when precisely the same familiarization objects are presented under different auditory conditions, infants fail to form object categories. First, when the familiarization objects are introduced with phrases that include no novel word (e.g., "Look at that!"), 12-month-olds fail to form categories (Waxman & Markow 1995). Second, when different novel words are applied to each familiarization object (e.g., "Look at the blick!"; "Look at the toma!"; "Look at the modi!"), they fail to form categories (Ferguson et al. 2015, Waxman & Braun 2005, Waxman & Markow 1995, Xu 2002). Third, not all consistently applied signals promote categorization. Instead, this link is specific to language: When the familiarization objects are paired consistently with signals outside the linguistic domain (e.g., tone sequences), infants fail to form categories (Balaban & Waxman 1997, Fulkerson & Waxman 2007).

Thus, by their first birthday, infants successfully cull novel words from the ongoing stream of speech, track whether the same (or different) words have been applied to a set of objects, and expect that a series of distinct objects named consistently with the same word share commonalities.

This expectation cannot be reduced to a simple associative mechanism (Waxman & Gelman 2009). After all, although both tone sequences and naming phrases have been applied with the very same consistency to the very same sets of familiarization objects, only infants listening to language successfully form object categories. The claim in this case is not that an infant's ability to form an object category depends entirely on listening to language. This claim is clearly false: Even without listening to language, preverbal infants and nonhuman animals successfully form some object categories, although this typically requires a considerable number of learning trials (for reviews, see Mareschal & Quinn 2001, Smith et al. 2012). Instead, the claim is both measured and precise: For human infants, words are invitations to form categories. Naming a set of distinct objects with the same name (e.g., "Look at the blick!") effectively highlights commonalities among them, commonalities that go undetected in the absence of naming (e.g., "Look at that!") (Althaus & Plunkett 2016, Waxman & Markow 1995). This invitation is in place early enough to support infants' first forays into building a lexicon (Bergelson & Swingley 2012, Tincoff & Jusczyk 2012) and to support their acquisition of fundamental representations of kinds, relations, and individuals (Dewar & Xu 2007, Waxman & Lidz 2006, Yin & Csibra 2015).

But this link between words and object categories, expressed so clearly by 12 months of age, does not remain constant across development. Instead, it provides the foundation upon which infants will subsequently build the more precise links that are the hallmark of human language. Infants will discover not only distinct words (e.g., "dog" and "chasing"), but also distinct kinds of words (e.g., nouns and verbs); they will also discover that distinct kinds of words are linked to distinct kinds of underlying meaning (e.g., nouns and object categories; verbs and event categories or relations). Importantly, these more precise links do not emerge all at once; they unfold in a cascading fashion. For infants in their first year, any consistently applied novel word, whether it is presented as a noun, adjective, or verb (e.g., "Look at the blick!"; "Look at the blick one!"; "Watch it blick!"), highlights a wide range of commonalities, including those that underlie object categories (e.g., dog versus horse), object properties (e.g., red versus green; soft versus sharp), or relationships among objects (e.g., chasing versus fleeing). At roughly 13 months of age, however, infants begin to establish a more precise mapping; they first tease apart the nouns from the other grammatical forms and link them specifically to categories of objects (e.g., dog), but not to properties of objects or events (e.g., green, chasing) (Waxman 1999). Next, with a noun–category link in place, infants go on to establish precise links for the predicates, including adjectives and verbs. Evidence that this developmental cascade begins with infants' discovery of a noun–category link converges well with linguistic evidence that discovering the meaning of a predicate depends in part upon the nouns that they take as arguments (Gleitman et al. 2005, Klibanoff & Waxman 2000, Mintz & Gleitman 2002, Waxman & Lidz 2006).

From this perspective, then, the 12-month-olds' link between language and cognition serves as an engine that catalyzes subsequent language and conceptual development. Notice that, because these increasingly precise links unfold in a cascading fashion, the cognitive consequences of naming will evolve rapidly and systematically over the first 2 years of life, depending upon how far along an infant is in the developmental cascade.

But what does this increasingly precise link between language and cognition afford the infant? Recent evidence has shown that it unlocks representational capacities that distinguish human cognition from that of our evolutionary relatives.

Language and Systems of Core Knowledge

Human infants share basic representational capacities with nonhuman animals. In particular, there appear to be hardwired systems for representing objects, tracking numerosity, navigating in space, perceiving causation, and detecting agency (for reviews, see Baillargeon et al. 2016, Carey 2009, Spelke & Kinzler 2007). Several of these systems, in turn, appear to operate within encapsulated modules. That is, the output of a module or computation is encapsulated from information represented elsewhere in the cognitive system. For example, adult-like representations of number are composed of one module dedicated to approximating large ratios and another dedicated to tracking a small number of individuals (Feigenson et al. 2004). Similarly, representations of large-scale space and how to navigate within it are comprised of one module dedicated to orienting via the geometry of a landscape and another dedicated to orienting via particular landmarks (Lee et al. 2006). Distinct, encapsulated modules like these are the foundations of core knowledge, and they serve as building blocks for higher-order cognition. But if humans and nonhumans alike share these basic building blocks, then why do humans' representational capacities so far exceed those of other species? The key, as George Miller suggested, is that humans' representational systems are intertwined with their communication system—language.

More specifically, researchers working from the core knowledge perspective have proposed that it is language that permits humans to weave together otherwise encapsulated representations within core knowledge systems, and that this connection among representations (along with the combinatorial capacity it affords) is the gateway to higher-order, abstract representations (Carey 2009, Spelke 2017). Beginning in infancy, human language boosts the representational capacities of core knowledge by translating otherwise encapsulated representations into a shared language-like format. These shared representations scaffold subsequent conceptual advancements. There is especially compelling evidence for the role of language in augmenting our representations of object, number, and space. For instance, the object representations of prelinguistic infants and nonhuman animals are characterized by coarse-grained spatiotemporal criteria, including cohesion (objects move as bounded wholes), continuity (objects move on unobstructed paths), and contact (objects do not interact at a distance) (Aguiar & Baillargeon 1999, Spelke 1990). Learning words for objects and object kinds permits infants to represent objects in a more finely grained, conceptually rich format (for reviews, see Waxman & Gelman 2009, Xu 2007). Likewise, as mentioned above, the numerical representations of prelinguistic infants and nonhuman animals occur in two distinct modules, one that approximates ratios among large quantities and another that specifies exact quantity in small sets (with a limit that appears to be three) (Feigenson et al. 2004). However, with the acquisition of language (specifically, learning number words and aligning them with sets), it becomes possible for infants to combine these otherwise distinct representations and to represent numbers, small and large, with exactness (Condry & Spelke 2008).

Evidence from deaf individuals deprived of language input from birth goes one step further, suggesting that language is a causal force bridging otherwise distinct representations and representational formats. For example, deaf children born to hearing parents do not receive the richly structured linguistic input that their counterparts (hearing infants of hearing parents or deaf infants of deaf parents fluent in sign language) receive. In the absence of this linguistic input, deaf children of hearing parents create their own unique gestural system known as homesign. Remarkably, homesign exhibits many fundamental features of more fully developed languages (e.g., American Sign Language or English). However, a fuller and more richly structured linguistic system emerges only when homesign systems are shared among a community of signers (for a review, see Goldin-Meadow 2017). Without access to such a richly structured linguistic system—one that includes words for representing precise number and precise spatial relations—homesigners appear to have difficulty representing exact quantities larger than three (Spaepen et al. 2011) and representing abstract spatial relations (Pyers et al. 2010).

Thus, research from the perspective of core knowledge suggests that language knits together distinct representational modules within and across otherwise encapsulated knowledge systems. In this view, language is what makes it possible to form the discrete, symbolic, and abstract representations that characterize the human mind.

Language as a Component of Natural Pedagogy

Infants' language and cognitive development do not occur in a vacuum. Instead, a signature of human development is that infants and their caregivers interact in rich social-communicative contexts. From the first days of life, infant–caregiver interactions are reciprocally social, filled with face-to-face communication, turn taking, and other communicative cues (e.g., eye gaze, infant-directed intonation, pointing). Social exchanges like these, which are especially engaging for infants, are the stage upon which language and conceptual development unfold (for reviews, see Csibra & Gergely 2009, Kuhl 2007, Vouloumanos & Waxman 2014).

Csibra & Gergely (2009) have proposed a theory of natural pedagogy to capture the effects of this broader set of communicative cues in infancy. In their view, the power of language comes, at least in part, from its social-communicative status. In this account, the effects of language [and especially infant-directed speech (IDS)] are on par with the effects of other ostensive social-communicative cues, including eye gaze and pointing. From the perspective of natural pedagogy, human infants are prepared by evolution to favor ostensive information conveyed by a pedagogical partner, to interpret ostensive cues as referential, and to expect that these cues signal kind-relevant, generalizable information.

There is now considerable evidence not only that infants are sensitive to ostensive cues, but also that such cues boost infant learning beyond what they could glean from observation alone and, in this way, boost human infants' learning in ways that are unavailable to nonhuman species (for reviews, see Csibra & Gergely 2009, Csibra & Shamsudheen 2015). For example, infants use ostensive cues to learn about referential gaze (Senju & Csibra 2008, Senju et al. 2008), to make inferences about the identity and location of hidden objects (Moll & Tomasello 2004), and to learn from novel cues (Wu et al. 2014). Infants' attention to ostensive cues also guides their memory and learning. For instance, if a caregiver points to an object that then disappears, infants remember what the object looked like but not its precise location; in contrast, if a caregiver reaches for an object that then disappears, infants remember its location but not what it looked like (Yoon et al. 2008). Likewise, if a caregiver introduces an object with IDS, infants can better identify that object's category membership even in the presence of conflicting surface features; if the object is introduced without IDS, infants are more likely to be distracted by conflicting surface features and to have more difficulty focusing on object kind (Kovács et al. 2017).

Language stands out as an especially potent ostensive cue. In the first year of life, infants expect that language, but not nonlinguistic signals (e.g., coughs, laughs), is a medium through which we share knowledge, beliefs, and intentions (Martin et al. 2012; Vouloumanos et al. 2012, 2014). By 12 months of age, infants' neural responses to images of an object vary as functions of whether they know the object's name (Gliga et al. 2009). By 14 months of age, infants' expectations in the context of naming are quite abstract. In one experimental design, 14-month-olds observed an actor produce an unconventional act: She turned on a light using her head, rather than her hands. Infants were then invited to turn on the light themselves. The way that they did so varied as a function of whether the event was named. If the actor provided a label for her unconventional act ("I'm going to blick"), infants imitated her behavior precisely, turning on the light with their heads. However, if the actor provided no such label ("Look at this"), infants turned on the light in a more conventional fashion, using their hands (Chen & Waxman 2013, Gergely et al. 2002).

The theory of natural pedagogy thus offers a compelling description of infants' sensitivity to social-communicative cues and the consequences of these cues for streamlining learning. It also dovetails with decades of evidence that language supports infants' ability to form categories (Waxman & Gelman 2009, Waxman & Markow 1995).

However, over the course of the first 2 years of life, infants' responses to human language part company with their responses to other ostensive, communicative signals like eye gaze and pointing. Even before they can combine words on their own, infants discover that there are distinct kinds of words and phrases; they also pinpoint with increasing precision how distinct kinds of words map onto distinct kinds of meaning (Waxman & Gelman 2009). In contrast, infants' responses to eye gaze and pointing do not follow this developmental trajectory. Although eye gaze and pointing may direct an infants' attention to one object or event over another, neither of these signals has the precision to specify which aspect of the scene an infant should attend to. This kind of precision is a feature reserved for human language.

DEVELOPMENTAL ORIGINS OF THE LANGUAGE–COGNITION LINK

The evidence reviewed above showcases several different ways in which language does, indeed, exert a hidden power on infant cognition. But how do infants come to link language and cognition in the first place?

To address this question, researchers have sought to identify how, and how early, infants begin to link language and cognition: What capacities, perhaps innately endowed or evolutionarily specified, are available to infants in the first months of life and how are they shaped by maturation and experience? Research on this topic, itself in its infancy, has been inspired not only by theories of language and cognitive development, but also by elegant studies of perceptual development. Before describing the evidence for the developmental origins of the language–cognition link, we set the stage by describing how infants tune their perceptual systems to the auditory and visual signals of our species.

Tuning to the Signals of Our Species

Human infants are certainly born altricial, but they are just as certainly not born as blank slates. Instead, within hours of their birth, infants reveal strong perceptual preferences and perceptual discriminatory capacities. These early perceptual capacities—evident in auditory, visual, and cross-modal perception—start out broad at birth and are then rapidly tuned in response to infants' postnatal experience. There is wide agreement that this process of perceptual narrowing is a domain-general one: The same fundamental learning processes guide infants' tuning within and across modalities (for reviews, see Maurer & Werker 2014, Scott et al. 2007).

At birth, infants' perceptual preferences and capacities in the auditory domain are broad. Newborns equally prefer listening to human and nonhuman vocalizations over other sounds (Vouloumanos et al. 2010), and they can distinguish among sounds across human languages (Werker & Tees 1984) and nonhuman primate vocalizations (Friendly et al. 2013a). Within their first months, infants' broad preferences narrow specifically to human language (Vouloumanos et al. 2010). Similarly, within their first year, infants' perception of native language sounds becomes sharpened, while their perception of nonnative language and nonhuman primate sounds concomitantly decreases (Friendly et al. 2013a, Werker & Tees 1984).

Perceptual narrowing, evident in infant behavior and neural activity (Kuhl & Rivera-Gaxiola 2008, Shultz et al. 2014), has been documented not only in speech perception, but also in infants' face perception and intermodal perception (for a review, see Maurer & Werker 2014). Homing in on voices, faces, and the correspondences between familiar voices and faces results in the integration of multisensory systems (Bruderer et al. 2015, Lewkowicz & Ghazanfar 2009). Within and across diverse perceptual systems, infants' initially broad preferences and discriminatory capacities become increasingly specialized for processing certain signals, chief among them the voices and faces of members of their own communities. Tuning processes like these are advantageous for infants because they increase the signal value for communicative signals available in their communities. Moreover, perceptual narrowing within and across perceptual modalities proceeds with no conscious effort required from the learner (Kraus & Slater 2016). In essence, then, even before infants begin to speak, they establish increasingly precise, efficient, and integrated perceptual systems.

The phenomenon of perceptual narrowing showcases the dynamic interplay between infants' impressive perceptual abilities at birth and their responsivity to postnatal experience. Especially compelling evidence comes from exposure studies. There are two classes of such studies. Studies in the first class examine natural variation in exposure (to language or faces) to identify how it shapes infants' perception. For instance, a classic experiment by Werker & Tees (1984) demonstrated that the particular language to which infants are exposed shapes their sensitivity to the sounds of that language. Likewise, Bar-Haim et al. (2006), Kelly et al. (2005, 2007), and Quinn et al. (2002) showed that the particular faces to which infants are exposed shape their sensitivity to the features of those faces.

Studies in the second class have adopted an even more direct approach, systematically manipulating infants' exposure to various stimuli. For example, providing infants with exposure to nonnative phonemes (Maye et al. 2002), nonnative musical rhythms (Hannon & Trehub 2005), monkey vocalizations (Friendly et al. 2013b), monkey faces (Fair et al. 2012, Pascalis et al. 2005), or other-race faces (Heron-Delaney et al. 2011) enables them to make distinctions among these signals, even months after they had tuned their perception specifically to signals in their native environment. Studies that provide infants with prolonged exposure, typically throughout the developmental window in which perceptual narrowing would occur, reveal that this exposure can maintain a developmentally prior perceptual ability (Pascalis et al. 2005). Similarly, studies that provide infants with brief exposure, even for only a few minutes and at an age beyond which perceptual narrowing has occurred, reveal that this exposure can reinstate a developmentally prior perceptual ability (Fair et al. 2012). Whether prolonged or brief, however, exposure must occur at key developmental junctures that correspond to infants' sensitive periods (Doupe & Kuhl 1999, Werker & Hensch 2015).

This work highlights human infants' plasticity at the behavioral and neural levels. Yet experience is not the only factor that guides perceptual narrowing; the effects of experience are often tempered by infants' maturational status. Evidence for an interaction between experience and maturation comes from comparisons between full-term and preterm infants. Because preterm infants are born early, they are exposed to language and faces (outside the womb) earlier than are full-term infants of the same maturational age. Comparisons between full-term and preterm infants have been instrumental in disentangling the relative contributions of experience and maturation across several perceptual domains, and collectively, these comparisons paint a nuanced picture. Infants' tuning of some perceptual capacities depends upon their maturational status [e.g., rhythmic and phonemic perception (Peña et al. 2010, 2012), luminance contrast (Bosworth & Dobkins 2009)], but tuning of other categories emerges primarily in response to postnatal experience [e.g., phonotactic acquisition (Gonzalez-Gomez & Nazzi 2012), chromatic contrast (Bosworth & Dobkins 2009)]. These findings help explain how subtle differences in developmental timing may amplify later differences.

Although tuning processes are ubiquitous throughout the animal kingdom (Lorenz 1937), the degree of tuning in humans far surpasses that observed in other species (Zangenehpour et al. 2009). Ultimately, perceptual tuning is adaptive, ensuring that human infants increasingly direct their attention toward the signals of our species, especially those who serve as their communicative and pedagogical partners (Vouloumanos & Waxman 2014, Vouloumanos et al. 2009).

However, the evidence for perceptual tuning cannot, on its own, reveal how language becomes linked to cognition. Addressing this question requires us to move beyond a focus on perception alone to consider how infants come to link the language they hear with the objects and events they observe in the world.

Beyond Perception: Tuning a Link Between Language and Cognition

Crucially, acquiring a human language and conceptual system requires more than tuning to the signals of its speakers. The power of human language derives from its links to cognition. In a recent line of work, researchers sought to identify how early infants begin to link language and cognition and to trace how this link unfolds in the first months of life. The results reveal that, by 3 months of age, infants not only prefer to listen to the communicative signals of our species, but have also established a principled and surprisingly early link between these signals and the fundamental cognitive process of categorization. Using the categorization task described above (see the section titled Words as Invitations to Form Categories), Ferry et al. (2010) discovered that, for infants as young as 3 months of age, listening to language (but not tone sequences) boosts object categorization.

Moreover, in the first months of life, language is not the only signal that exerts this advantageous cognitive effect. For infants at 3 and 4 months of age, vocalizations of nonhuman primates (in this case, those of the blue-eyed Madagascar lemur, *Eulemur macaco flavifrons*) also facilitate object categorization (Ferry et al. 2013). Unlike the link to human language, infants' early link between nonhuman primate vocalizations and cognition is short-lived; by 6 months of age, infants have tuned the link specifically to language (Ferry et al. 2013). The developmental timing of this tuning roughly corresponds to infants' brain responses to human and nonhuman vocalizations in their first months of life (Shultz et al. 2014).

Together, these findings provide several developmental insights. First, a link between human vocalizations and object categorization, evident at 3 months of age, derives from a broader template that initially encompasses vocalizations of both humans and nonhuman primates. Second, this initially broad template cannot be derived solely on the basis of experience. Despite the fact that, by 3 months of age, infants have had rich exposure to language but virtually no exposure to lemur vocalizations, these vocalizations confer the same cognitive advantage. Third, the cognitive advantage of listening to lemur vocalizations cannot be attributed to low-level acoustic features such as signal complexity: Infants listening to backward speech [the same speech segment used by Ferry et al. (2010) but played backward] fail to form object categories at any age. This outcome converges with the neural evidence that forward speech is processed differently than backward speech in the infant brain from birth (Dehaene-Lambertz et al. 2002). Fourth, by 6 months of age, infants tune this initially broad link specifically to human vocalizations. In effect, then, they home in on precisely those signals (human language) that will ultimately constitute the foundations of meaning.

Finally, although we now know that language boosts cognition throughout infants' first year, the mechanism underlying the language–cognition link at 3 and 4 months of age is still unclear. Because infants at 3 and 4 months of age are unable to parse words from the sentences in which they are embedded (Bortfeld et al. 2005, Jusczyk & Aslin 1995, Seidl et al. 2015), it is unlikely that, at this age, words serve as invitations to form categories. What is more likely is that listening to language (and perhaps especially to IDS) engenders in young infants a kind of heightened arousal or attention to their surroundings, and that this promotes object categorization. This possibility converges well with cross-species ethological evidence indicating that certain privileged signals engage animals' attention (Owren et al. 2011, Vergne & Mathevon 2008). Perhaps, in very young infants, listening to language (like eye gaze) promotes learning by increasing arousal and attention, rather than by launching an explicit search for meaning. Before long, however, language will take off on its own unique developmental trajectory—one that allows infants to discover and generate precise kinds of meanings, in potentially infinite combinations, in a way that no other species can.

The evidence that infants have begun to link language and cognition in their first 6 months raises a new question: How do infants identify which signals in their environment to link to cognition in the first place?

Tuning the Language–Cognition Link: Developmental Mechanisms

Two recent series of studies have addressed this question, investigating the mechanisms by which infants establish and tune their precocious language–cognition link. Both series take as their methodological starting point the evidence concerning the influence of language and nonlinguistic signals (e.g., lemur vocalizations, backward speech, tone sequences) on infant object categorization (Balaban & Waxman 1997; Ferry et al. 2010, 2013; Fulkerson & Waxman 2007). Together, these studies suggest that there may be two distinct routes for tuning the language–cognition link in infants' first 6 months, one for tuning the initially privileged signals (human and nonhuman primate vocalizations) and another for establishing new links for signals that fall outside infants' initial template (tone sequences).

Tuning initially privileged signals: the effect of exposure. Using an exposure paradigm inspired by those pioneered in the perceptual tuning literature, Perszyk & Waxman (2016) systematically manipulated infants' exposure to lemur vocalizations. Infants in the exposure condition listened to 2 minutes of lemur vocalizations, embedded in a soundtrack of instrumental music. Immediately after this period of passive exposure, infants were engaged in the categorization task. Merely exposing 6- and 7-month-olds to lemur vocalizations permitted them to reinstate the developmentally prior link between this signal and object categorization. Moreover, this was more than a fleeting phenomenon. Another group of infants listened to lemur vocalizations for 6 weeks, beginning at 4 months of age and lasting until they were 6 months of age. At 6 months, infants were brought into the lab to participate in the categorization task. Although at the time of their lab visit these infants had not heard a lemur vocalization for days, they nonetheless successfully formed object categories. This reveals that merely exposing infants to lemur vocalizations—an initially privileged signal—has a robust and long-lasting effect. In contrast, exposing infants to backward speech had no effect on their success in the categorization task. This reveals that passive exposure to signals outside infants' initial template does not permit them to forge a new link to cognition.

Moreover, the effect of exposure appears to be constrained by infants' maturational status. To disentangle the effects of infants' experience listening to language and their maturational status, Perszyk et al. (2017) compared full-term and preterm infants' responses on the object categorization task while listening to language. Preterm infants showed precisely the same patterns as their full-term counterparts when they were matched for maturational age. This outcome converges with evidence from studies of speech perception (Peña et al. 2010, 2012), but takes the field one step further: Exposure is gated by maturation not only as infants tune to the signals of their language, but also as they link those signals to cognition.

These results illustrate that infants' experience with the signals in their ambient environment, together with their maturational state, guides them as they forge increasingly precise links between the sounds they hear and the core cognitive processes that will ultimately serve as foundations of meaning. Importantly, the effect of exposure is evident only for the signals in infants' earliest template: human and nonhuman primate vocalizations. Exposure alone does not permit infants to create, de novo, a link between cognition and an otherwise inert signal (e.g., backward speech or tone sequences).

This evidence also raises a new question. A hallmark of human communication is our remarkably flexible capacity to infuse otherwise nonlinguistic signals, like tone sequences (e.g., Morse code) and smoke signals, with communicative status. Does this flexible appropriation of new signals rest upon a fully developed system of language, or is it available to infants?

Establishing new links to cognition: the effect of social-communicative exchanges. There is now converging evidence that infants as young as 6 months of age can, in fact, forge a new link between a nonlinguistic signal and cognition, but only if the signal is embedded within a rich social-communicative exchange (Ferguson & Lew-Williams 2016, Ferguson & Waxman 2016b). For example, Ferguson & Waxman's (2016b) design takes as its starting point infants' object categorization while listening to tone sequences. Recall that tone sequences (like backward speech) consistently fail to promote object categorization throughout the first year (Balaban & Waxman 1997, Ferry et al. 2010, Fulkerson & Waxman 2007). Ferguson & Waxman systematically manipulated 6-month-old infants' exposure to tone sequences. By design, and in sharp contrast to the passive exposure phase in Perszyk & Waxman's (2016) paradigm, in this case the exposure phase was decidedly social and communicative. Before participating in the categorization task, infants watched a videotaped dialogue between two young women, one speaking in English and the other responding by beeping in sine-wave tone sequences (which were dubbed). Simply observing this 2-minute dialogue between the speaker and the beeper had a remarkable effect: 6-month-olds now successfully formed object categories while listening to tone sequences. Yet when the very same tone sequences were uncoupled from the social-communicative exchange, infants failed to form categories in the subsequent categorization task. Thus, infants as young as 6 months of age are sufficiently flexible to link an otherwise arbitrary signal to cognition, but they make this link only if the arbitrary signal is embedded within a rich social-communicative interchange. This outcome, which has now been documented for both object categorization and abstract rule learning (Ferguson & Lew-Williams 2016), converges with evidence for the power of communicative ostensive cues on infant cognition (see also Csibra & Gergely 2009).

Mechanisms of tuning the language–cognition link: two distinct routes. Considered together, these results suggest there are (at least) two routes by which young infants forge a connection between communicative signals and core cognitive capacities like categorization and abstract rule learning. For signals that are part of infants' initial template (e.g., human and nonhuman primate vocalizations), mere exposure is sufficient to either maintain or reinstate a developmentally prior link to cognition (Perszyk & Waxman 2016). In contrast, for signals that fall outside infants' initial template (e.g., tone sequences, backward speech), a different route is required: Infants link otherwise arbitrary signals to cognition only if they are embedded within a rich social-communicative interchange (Ferguson & Lew-Williams 2016, Ferguson & Waxman 2016b, May & Werker 2014, Namy & Waxman 1998, Woodward & Hoyne 1999).

FUTURE DIRECTIONS AND CONCLUSIONS

In this article, we have reviewed the developmental origins and unfolding of a link between language and infants' core cognitive capacities. A goal for future work will be to broaden the empirical and theoretical base and to bring the behavioral evidence into closer alignment with new evidence from evolutionary theory and developmental neuroscience. For example, how do infants' neural responses to the signals that are included in their initially broad template differ from those that are outside this initial template? How do infants' neural responses to these signals change as infants increasingly tune this link?

Bridging Infant Cognition and Evolutionary Theory

The possibility that infants have at their disposal two distinct routes for linking communicative signals and core cognitive capacities brings to mind recent neuroscientific claims that there are dual pathways underlying various communication systems. For example, Owren et al. (2011) and Ackermann et al. (2014) propose a dual pathway model for human acoustic communication, arguing that speech production engages two separate neuroanatomic channels. One channel, shared among primates, reflects subcortical mechanisms that support affective vocalizations (e.g., for nonhumans, warning or mating calls; for humans, affective intonation). A second channel, specific to humans, reflects cortical mechanisms that support articulate speech. Similarly, Senju & Johnson (2009) propose a dual pathway model of human eye gaze communication. They argue that a subcortical route, which may have served the evolutionary function of signaling social rank (Gobel et al. 2015), is augmented in humans by a more elaborate cortical route—a social brain network—which may serve the more precise, human-specific function of identifying communicative or pedagogical intent (Senju & Csibra 2008, Senju & Johnson 2009).

Although it is possible that these dual pathway models are related to the developmental evidence we have described in this review, this is, at best, speculative. Perhaps infants' initially broad link between cognition and communicative signals—including both human and nonhuman primate vocalizations—corresponds to an ancestral route that confers its cognitive advantage via primate-general affective and attentional neural systems. Perhaps infants' capacity to link new signals, including tone sequences, by embedding them within social-communicative dialogues corresponds to a human-specific route. This human-specific route may be built upon the ancestral route but may confer its cognitive advantage via more recently evolved neural systems. This possibility is related to documented parallels between human evolution and development for cortical expansion (Hill et al. 2010).

Bridging Infant Cognition and Developmental Neuroscience

Infants' neural responses to both language and objects have received considerable attention (e.g., Csibra et al. 2000; Grossmann et al. 2009; Kaufman et al. 2003, 2005; Kuhl & Rivera-Gaxiola 2008; Quinn et al. 2006; Southgate et al. 2008). More recently, developmental neuroscience has sought to identify neural signatures underlying the language–cognition interface in infants. Although this work is itself in its infancy, there are hints that infants' neural responses converge with the behavioral evidence documenting the effects of naming on cognition. For example, by 9–12 months of age, infants' neural responses to objects vary systematically as a function of whether they are named correctly (Friedrich & Friederici 2010, Parise & Csibra 2012). Gliga et al. (2009) provide more direct neural evidence for a link between naming and object representation: At 12 months of age, infants' neural responses to objects vary as a function of whether they know a name for the objects—even when they are viewing those objects in the absence of their names. This outcome precisely mirrors the behavioral evidence that naming objects (presented consistently during familiarization) influences infants' attention to new and as-yet unnamed objects (presented in silence during the test) (Waxman & Markow 1995).

Because the earliest neural evidence concerning the language–cognition link currently comes from infants at 9 months of age, this work cannot yet shed light on the neural processes underlying infants' earliest language–cognition links or how they unfold in the first 6 months. By harnessing the now considerable behavioral evidence to state-of-the-art techniques in developmental neuroscience, researchers may illuminate how infants' brain systems interact in their first months and how they are sculpted by experience. In our view, the most exciting frontiers will be those that bring the rich theoretical framework on speech processing—thus far proposed for adults (for review, see Giraud & Poeppel 2012)—to investigations of infant development. If the past is a prologue to the future, we suspect that focusing on cascading neural oscillatory activity (Goswami 2011, 2016) will be an ideal avenue for identifying the developmental origins and unfolding of the links between language and cognition in young infants.

SUMMARY

In this article, we have reviewed evidence that illuminates the developmental origins of infants' precocious language–cognition link, how it unfolds, and how it advances infants beyond their initial perceptual and conceptual capacities. The evidence reveals that even before infants can recognize the sound of their own names, links between language and cognition are in place. Infants' earliest link, evident by 3 months of age (Ferry et al. 2010), is part of a broader initial template that includes both human and nonhuman primate vocalizations. This indicates that human development is shaped not only by experience, but also by capacities inherent in the infant: Although 3-month-olds have acquired considerable exposure to human language and virtually no exposure to nonhuman primate vocalizations, both signals confer the same cognitive advantage. At 6 months of age, when infants have tuned this link specifically to human vocalizations (Ferry et al. 2013), they nonetheless remain sensitive to experience: Passive exposure to nonhuman primate vocalizations permits infants to maintain or reinstate a link between this signal and cognition (Perszyk & Waxman 2016). However, for signals that fall outside of infants' initial template (backward speech, tone sequences), passive exposure alone is insufficient to create a new link to cognition (Ferguson & Waxman 2016b, Perszyk & Waxman 2016). Instead, signals like these must be embedded within a social-communicative context (Ferguson & Waxman 2016b). Thus, there appear to be at least two routes by which infants can link signals to cognition in their first year of life. This combined evidence illustrates the joint contributions of infants' innate capacities and their sensitivity to experience, highlighting how a precocious link between language and cognition advances infants beyond their initial perceptual and conceptual capacities.

This early emerging link between language and cognition also makes possible a suite of conceptual and representational capacities that distinguish human cognition from that of our evolutionary relatives. In infants' first year, language takes the lead among the other ostensive cues, enabling infants to learn far more than they could from observation alone. Language also enables infants to weave together representations from otherwise distinct systems of knowledge. These links between language and cognition are the gateway to advancing core systems of knowledge and establishing the higher-order, abstract representations that are the signature of human cognition (Carey 2009, Spelke & Kinzler 2007).

Perhaps most importantly from a developmental vantage point, we have argued that the language–cognition link is not a steady state. The information an infant gleans from listening to language will vary as a function of their developmental status and the precision of their language–cognition link at that time. In their first months, simply listening to language boosts cognition (Csibra & Gergely 2009, Ferry et al. 2010). A few months later, the consequences of listening to language become considerably more nuanced and more powerful as infants discover increasingly precise links between language and concepts. A constellation of factors that are unique to human development—infants' prolonged period of dependency, exquisite sensitivity to experience, and powerful learning strategies—collectively spark a cascade of developmental change whose ultimate result is the acquisition of language and its unparalleled interface with cognition.

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