II Language and Theory of Mind

7 Infants' Early Competence for Language and Symbols

Ghislaine Dehaene-Lambertz, Ana Fló, and Marcela Peña

Overview

Humans have much more sophisticated communication skills than other species. They are not limited to emotional cries, alarm calls, and soothing demands; they also interpret the inner and outer world in a symbolic way, resulting in a collective intelligence and an accumulation of knowledge called culture. This culture permeates the child and fosters efficient learning, based on the knowledge accumulated through generations. To develop this collective intelligence, it requires (a) a social brain predisposed to learn from conspecifics, (b) awareness of one's mental state and knowledge and those of others, (c) a shared common language of thought, and (d) a communication system for exchanging this information. We insist on the value of symbolic representations as a compressed, necessary format for representing information to ourselves and exchanging information with others. We propose that human cognition has been boosted beyond the cognition of other primates by the multiplicative advantage of codevelopment of social cognition, language but also symbolic thinking that can be observed from the first months of life on.

Introduction

Humans are constantly looking for rules and causal relationships to explain what has happened and predict what will happen. Collaborative thinking in adults allows a significant improvement in prediction accuracy (Bahrami et al., 2010), but collaborating with others requires, on the one hand, having explicit representations of the problem to resolve and, on the other hand, knowing that it is possible to share these representations unambiguously with another mind. This shared cognition implies a set of symbols

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that efficiently summarize the concepts we want to represent first to ourselves and second to share with others, but also an implicit assumption that the other can understand these symbols in order to capitalize on each other's knowledge. Thus, beyond a theory of mind, this shared cognition requires a pedagogical stance, as proposed by Csibra and Gergely (2009). This pedagogical capacity might have existed since the ancient hominins, if we accept the Oldowan stone tool industry (2.34 million years ago) (d'Errico & Banks, 2015) as one of the oldest testimony of collective elaborated production. But how does it begin in infants?

A Symbolic Brain

In the flow of thoughts, to isolate relevant information that could be shared with others, it is necessary to summarize and discretize sensory information. A first step is to gather different objects sharing common characteristics into a single category, but a more powerful operation would be to further compress this information into a single arbitrary symbolic form. Humans are particularly skilled at creating and using symbolic systems: music notation, traffic signs, equations, even scarification and uniforms are simplified marks that summarize complex information. Language is the first symbolic system acquired by infants and the most productive and versatile. A word can condense the essence of an individual, a category of objects, an action, an abstract concept such as freedom. These symbols can be combined in logical operations such as addition, negation, exclusion, and quantification or even superimposed to create poetic effects. The symbolic power of language is evident in adult exchanges. Infants may also be sensitive to it very early on, when they listen to speech.

No one denies that words are arbitrary labels attached to a semantic concept, but the initial relationship between the label and the concept is disputed. It is conventionally assumed that, because a label is produced associated with an object, infants first learn about the co-occurrence of these two events, the labels being only another characteristic of the object, like the sound it makes when it falls. Gradually, infants understand that the label can be used to refer to the object. Instead, we propose that infants immediately use the label as an internal variable that stands for the object.

We also propose that this variable is explicit, at a high-level node that establishes contact between a global workspace and domain-specific modules.

Because of the location of symbols at a higher-level, infants can explicitly and consciously control their use of labels, notably to share and receive information. They can also use them to combine concepts calculated in underlying modules, such as "to the left of the blue wall," generating new unitary representations (Hermer-Vazquez, Spelke, & Katsnelson, 1999). We support our proposal by examining comparative brain anatomy, a reinterpretation of published studies in infants, and recent studies directly testing the hypothesis of an early symbolic system.

Development of the Frontal Areas in Humans

Symbolic representations and manipulation are assumed to be supported by frontal areas (Nieder, 2009). Indeed, when adult humans and macaques listen to the same tone sequences that vary in either the number of tones or the structure of the sequence, both species detect the changes, but only in humans is the left inferior frontal gyrus, a common region, activated by both changes. This result was interpreted as evidence of a more abstract "change" code in humans compared with the simple response of discrimination in each specific module in macaques (Wang, Uhrig, Jarraya, & Dehaene, 2015).

These cross-species computational differences are supposed to be supported by the expansion of the associative areas of the frontal lobe, the inferior parietal and the posterior part of the superior temporal regions (Chaplin, Yu, Soares, Gattass, & Rosa, 2013), in parallel with the development of large tracts connecting the frontal areas to all other lobes, such as the arcuate fasciculus with the inferior parietal and the superior temporal regions. The major difference in connectivity between macaques and humans is the large connectivity of the inferior frontal regions with the associative auditory cortices in humans (Neubert, Mars, Thomas, Sallet, & Rushworth, 2014).

These particularities are already observed during gestation. The development of the modern human brain differs significantly from monkeys and even from older humans. In particular, its prolonged maturation over many years increases the period of plasticity. Unlike chimpanzees, human fetuses retain rapid brain growth after 22 weeks of gestation, which persists even up to two years (Sakai et al., 2012; DeSilva & Lesnik, 2006; Coqueugniot, Hublin, Veillon, Houet, & Jacob, 2004; Neubauer, Gunz, & Hublin, 2010). During that period, the prefrontal cortex develops faster than the rest of the brain, again unlike chimpanzees (Sakai et al., 2011). Even compared with ancient *Homo sapiens,* the globular shape of the modern human brain is more pronounced, and it develops mainly after birth. Endocasts of *sapiens* and Neanderthal newborns are not very different, while adult shapes differ due to the enlargement of integration cortices (Neubauer, Hublin, & Gunz, 2018; Gunz, Neubauer, Maureille, & Hublin, 2010).

However, because of their slow maturation, associative regions have long been thought to be poorly functional at a young age, and the role of frontal regions in infant cognition has been underestimated. Yet several functional magnetic resonance imaging (fMRI) studies have shown early activation in these areas. Moreover, as any other brain region, the frontal lobe is never activated as a whole but is parceled into regions that show functional similarity with adult responses. For example, when short-term verbal memory is required, inferior frontal regions are involved (Dehaene-Lambertz, Dehaene, & Hertz-Pannier, 2002) whereas attention to long-term memory content depends on more dorsal regions (Dehaene-Lambertz et al., 2006). Similarly to adults, the balance between medial prefrontal and orbitofrontal regions is observed in infants when a familiar rewarding stimulus, such as the maternal voice, and a new and unknown stimulus with a value to evaluate, such as the voice of another mother, are presented (Dehaene-Lambertz et al., 2010).

Frontal areas are not only at the top of a hierarchy of a bottom-up flow of information, they also send feedback information to improve perception and direct learning. The hierarchical organization of brain areas defined by the relative proportion of neurons in supragranular (contributing to feed-forward pathways) and infragranular (contributing to feedback pathways) layers is observed since gestation in primates. Feed-forward axons reach the correct target before the end of gestation. By contrast, feedback connectivity is exuberant and progressively pruned after birth (Price et al., 2006). Evidence of top-down activity has been observed with near-infrared spectroscopy in eight-month-old infants who were exposed to pairs of a tone followed by a smiley. From time to time the smiley was absent, but a response in the visual areas was recorded nevertheless, revealing that infants were expecting the image (Emberson, Richards, & Aslin, 2015). Other experiments using electroencephalography also have shown complex expectations from infants at five months (Kabdebon & Dehaene-Lambertz, 2019) and twelve months (Kouider et al., 2015) after they have learned arbitrary sound–image associations.

Frontal neurons through long-distance connectivity participate in a powerful global workspace that offers the possibility of integrating the results of the computations of the many modular brain networks into a common space (Mesulam, 1998; Dehaene & Naccache, 2001). Information in this central space can be maintained for a long time, amplified, and combined with other information but at the cost of slow serial entries. Moreover, these entries can be consciously manipulated—that is, they become explicit for oneself and reportable to others.

The signature of this conscious space is an all-or-none response. If a stimulus dimension is linearly manipulated, such as the duration of presentation of a masked face, the sensory cortices follow the same linear response. In infants, the amplitude and duration of the P400 vary linearly with the duration of the face presentation. By contrast, later responses are only recorded when the stimulus is consciously perceived and not when it remains below the perception threshold displaying a characteristic all-or-none response. In adults, this conscious stage is reached in 300 milliseconds while it is around 1 second in infants (Kouider et al., 2013).

Therefore, the immaturity of the child's brain, which is often apprehended as a contrast between mature low-level regions and immature high-level regions, is more appropriately described as a dynamic competition between parallel circuits whose computational efficiency is controlled by maturation. Differences in the speed of local computations and information transfer can favor one circuit over the other, in particular to enter the global workspace and be amplified and integrated into explicit representations.

In summary, maturation extends over many years in humans, refining connectivity and accelerating local computations and information exchange between distant regions. However, the neural architectural design is fundamentally similar to that of adults, thus leading to identical or similar computational properties, but at a much slower speed. Notably abstract computations, such as the manipulation of symbols and the conscious access to mental representations, can be accessible even to very young children. Do we have evidence of such abilities?

The Power of Words in Infants

The first acquired symbolic system is language, and many studies have pointed out that infants by five to six months of age, if not earlier, might be equipped with a functional referent-label mapping mechanism. As early as six months, they have already noticed a few words and associate them with people ("mon" "dad," the infant's own name; Tincoff & Jusczyk, 1999), body parts (Tincoff & Jusczyk, 2012), and actions ("hug," "eat"; Bergelson & Swingley, 2012). In the laboratory, they easily learn to map arbitrary sounds to objects: at two months, infants can associate one syllable with one familiar object, for example. But very quickly they succeed in more complex tasks (Gogate, 2010; Gogate, Prince, & Matatyaho, 2009). Using event-related potential (ERP), Friedrich and Friederici (2011, 2017) reported that three-month-old and six-month-old infants were able to learn the mapping between eight words and objects. However, only older infants remembered the associations the next day, and sleep seems to be crucial for maintaining learning (Friedrich, Wilhelm, Born, & Friederici, 2015; Friedrich, Wilhelm, Molle, Born, & Friederici, 2017).

What do infants learn? A simple association or more than that? Naming an object helps children in many areas. Ten-month-old infants pay more attention to objects that have previously been named than to those that are silently presented or even pointed at (Baldwin & Markman, 1989). It is not only attention that is amplified but also categorization of objects and their memorization. In a series of behavioral experiments in very young children, Waxman and collaborators studied the influence of language on the formation of conceptual categories. Different objects or images belonging to the same category were successively presented to children of different groups and ages. The presentation was accompanied either by a sentence naming the object with a pseudo-word—"Look at the blicket"—or by musical tones, or in silence. During the test, the children were consistently far more able to distinguish between two new objects—one belonging to the familiar category and the other to a new category—in the naming condition (Waxman & Markow, 1995; Balaban & Waxman, 1997; Fulkerson & Waxman, 2007; Ferry, Hespos, & Waxman, 2010). These results suggest that naming invites children, as young as three months (Ferry, Hespos, & Waxman, 2013) to form conceptual categories that they would not have considered without the use of words. This learning can be postponed, and it can appear only after a sleep period. Only six- to eight-month-old infants who nap generalize the name of an object to other exemplars of the same category (Friedrich et al., 2017; Friedrich et al., 2015).

Labeling an object with a word also allows infants to represent several objects. Before the age of twelve months, infants have difficulty maintaining the simultaneous representation of several objects. For example, when two objects appear alternately from the back of an opaque screen, infants do not seem to expect two objects when the screen is removed (Xu & Carey, 1996). However, if each time the objects appear from behind the screen they are named by two different words, the infants are surprised when only one object is revealed. They are not surprised when the objects are designated by the same generic word "toy," or accompanied by two separate musical notes or sounds (Xu, 2002). The fact of naming each object specifically allows the individualization of the two objects.

Finally, labeling makes it possible to maintain more objects in working memory. In an experiment by Feigenson and Halberda (2008), four identical objects were hidden one by one in a box. The fourteen-month-old child must subsequently recover them, but two objects were surreptitiously removed by the experimenter. The time spent by the child searching for the two missing objects is then measured. In a first condition, the first two objects are named differently from the last two—"Look, a dax," then "Look, a blicket"—while in a second condition, each object is generically called "Look at this!" Children spend more time searching for missing objects when the experimenter has separated the four physically identical objects into two groups using two separate words than when he designates them with the same generic sentence. Young children can therefore use words to push the limits of their memory storage and thus memorize the four hidden objects, an ability that only appears much later in the absence of a name.

In these experiments, infants combine two interesting properties. They use speech as a source of valuable information about the world and use the label provided by speech to help them distinguish and memorize objects categories. What is the function of this label? Is it a powerful attention grabber because speech is a common and rewarding stimulus thanks to the social context in which it is embedded? Or does the label have a symbolic value, which enables it to represent a category in a very compressed form that can be more easily handled in the internal working space?

Are Words Symbols?

In a symbolic system, there is an equivalence relationship between the set of symbols and the set of objects the symbols stand for. Thus, unlike associative learning—in which if A is followed by B, it does not mean than B is followed by A—in symbolic learning there is no direction between A and B because the object A and the symbol B point toward the same representation. Ekramnia and Dehaene-Lambertz (2019) trained four-month-old infants in a naming task for two categories of images— "fribbles" versus flying birds. The pseudo-word "kafon" was presented, followed 1 second later by one of 180 images belonging to one category (e.g., birds) whereas "pauvou" was paired in the same way to the other category (e.g., fribbles).

After thirty trials, 10 percent of incongruent trials with a mispairing were introduced to verify the infants' learning. But also 20 percent of reversed trials were introduced, in which the object was presented first followed by the name (in 10 percent of cases, the pairing was correct and in the other 10 percent, incorrect). Incorrect pairs, whether in canonical or reversed trials, induced ERP responses of surprise. Because infants have built an equivalence between the category and the name, reversed and canonical pairs are the two sides of the same coin, a process very different from associative learning, which is directional.

Kabdebon and Dehaene-Lambertz (2019) went farther and showed that infants are also able to name algebraic rules. In a series of experiments, five-month-olds were trained to associate ever-changing trisyllabic nonce words characterized by the location of the repetition of a syllable (either immediate: AAB words; or on the edges: ABA words) with an image (a fish or a lion). In the test, infants were surprised by incongruent pairings both in canonical and reversed trials.

This immediate generalization to reversed trials without further training is not observed in animals (Medam, Marzouki, Montant, & Fagot, 2016), not even in chimpanzees (Kojima, 1984). Usually animals must learn separately both directions. This does not mean that symbols are not accessible to animals. For example, macaques can learn to represent quantities by abstract visual shapes, and they can even add these symbols and associate the result with the correct quantity (Livingstone et al., 2014; Srihasam, Mandeville, Morocz, Sullivan, & Livingstone, 2012). However, it is a very slow process. By contrast, the speed at which children learn these pairs and the spontaneous bidirectional mapping indicate another learning mechanism than simple slow associative learning, as was previously assumed in infants (Nazzi & Bertoncini, 2003).

These recent experiments suggest that human infants assume an isomorphism between an internal symbolic space and the external world. Therefore, if the experimenter uses two words, the infant assumes that she must discover two kinds, whereas one word implies that all the objects presented can be grouped together. Furthermore, infants' errors in the studies by Xu (2002) and Feigenson and Halberda (2008) may suggest that they are more attentive to symbolic representations than to sensory representations, probably because of the simpler manipulation and memorization relative to the overwhelming richness of sensation. It might also reveal that the format of representations in the central workspace is symbolic, and that in explicit tasks infants have access only to this format.

Speech, an Information Tool for the World

If external information can be summarized by a symbol, what can be considered a symbol by infants? Waxman and collaborators showed, first, that it is not enough to couple an image with any sound for the sound to represent the image category; and second, that younger babies are more tolerant and accept a greater variety of sounds than are older babies: If speech and lemur vocalizations (but neither tones nor backward speech) are relevant for three-month-old infants, this is no longer the case for lemur vocalizations at six months (Ferry et al., 2013). At this older age, English-speaking babies are also not helped by a distant foreign language (such as Cantonese) as opposed to a closer language (such as German) (Perszyk & Waxman, 2019). It therefore seems that they are progressing not in their symbolic competence but in their understanding of the communication medium accepted in their cultural environment.

Indeed, infants discover very early on that speech conveys information. In an eye-tracking experiment, Marno and colleagues (2015) presented four-month-old infants with a video of an experimenter fixating on them, who then directed his gaze to the right (or left) where an object would subsequently appear. Infants eyes moved more quickly toward the object when the experimenter was talking compared with a silent video or with a video accompanied by backward speech.

Martin and colleagues (2012) presented a brief situation of interaction between two experimenters and one-year-old children. During familiarization, a first person chooses one of the two objects presented, clearly indicating her preference for that object. In the next scene, the second experimenter faces the same two objects and interacts indifferently with each of them, without showing any preference. Finally, in the test phase, both people are present, but the objects are out of reach of the first person. She turns to the second and coughs for a first group of children or says "koba" for a second group. The second experimenter then gives her either her favorite object or the distractor. In the *word* but not in the *cough* condition, children were surprised when the second experimenter did not hand over the first experimenter's favorite object and therefore looked at them significantly longer. One-year-old children thus seem to expect that information about the target object was conveyed between the two experimenters by a word, unlike the cough noise. These results were subsequently replicated in six-month-old infants (Vouloumanos, Martin, & Onishi, 2014).

Even with an attention grabbing and highly natural activity such as singing, six- to eight-month-olds display fewer communicative behaviors (vocalization, visual contact, body movements, and synchrony of these behaviors with maternal interactive behavior) in face-to-face interactions than they do with a talking mother (Arias & Pena, 2016). Infants therefore perceive the communication dimension of speech and its role as providing information about the world.

If children have inferred that speech is a privileged channel of communication, given their daily experience, they can also accept another medium of communication if social exchanges have depicted its use. For example, if they see two women exchanging with ostensive social signals but one speaking and the other "beeping," six-month-old infants become able to use the "beeps" to identify a "dinosaur" category as opposed to "fish," unlike babies who have heard the same audio file but not correlated with the social exchanges (Ferguson & Waxman, 2016). This experiment illustrates the three key elements that support pedagogy in human infants: social cognition to figure out the communication medium, an ability to sort objects in categories, and a symbolic system to label any category. These three ingredients rely on different neural bases and codevelop during infancy. They allow infants to take advantage of other people's knowledge to identify relevant information in the environment and thus boost their learning.

If infants in the laboratory easily accept different types of labels (images, words, beeps, etc.) to represent a category, in everyday life the situation is much more complex. Infants must find out how their cultural group communicates (for example, oral or sign language), analyze this efficient but rich and complex communication system, and at the same time be attentive to the pertinent cues in their environment and correctly assign the proper label to the right object. The huge complexity of the task explains the apparent slowness of progress during the first years of life, and masks infants' early possibilities for symbolic representations.

Although early communication needs in infants make language the first domain in which symbols are used, symbolic representations go beyond language in adults. It is interesting to note that mathematical knowledge and verbal knowledge are clearly separated in the adult brain (Amalric & Dehaene, 2016), which calls into question the general capacity for symbolic representations versus an extension from an initial verbal domain to other domains.

Conclusion

To conclude, we have proposed that teaching, an important activity for both parents and children from the first few months of life, requires summarizing information in a compressed abstract format for an effective sharing between individuals, which thus implies symbolic representations. Although our hypothesis of symbolic representations in infants requires further experimental evidence, it parsimoniously explains several experimental results in the literature and is consistent with the brain imaging observations that have revealed a stronger continuity than previously thought in the functional cerebral architecture between infants and adults. The question of whether symbols are initially limited to the linguistic domain remains open, but we may postulate that symbols extend beyond language and might represent the required representation of information in a conscious workspace.

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References

Amalric, M., & Dehaene, S. (2016). Origins of the brain networks for advanced mathematics in expert mathematicians. *Proceedings of the National Academy of Sciences of the United States of America, 113*(18), 4909–4917.

Arias, D., & Pena, M. (2016). Mother-infant face-to-face interaction: The communicative value of infant-directed talking and singing. *Psychopathology, 49*(4), 217–227.

Bahrami, B., Olsen, K., Latham, P. E., Roepstorff, A., Rees, G., & Frith, C. D. (2010). Optimally interacting minds. *Science, 329*(5995), 1081–1085.

Balaban, M. T., & Waxman, S. R. (1997). Do words facilitate object categorization in 9-month-old infants? *Journal of Experimental Child Psychology, 64,* 3–27.

Baldwin, D. A., & Markman, E. M. (1989). Establishing word-object relations: A first step. *Child Development, 60*(2), 381–398.

Bergelson, E., & Swingley, D. (2012). At 6–9 months, human infants know the meanings of many common nouns. *Proceedings of the National Academy of Sciences of the United States of America, 109*(9), 3253–3258.

Chaplin, T. A., Yu, H. H., Soares, J. G., Gattass, R., & Rosa, M. G. (2013). A conserved pattern of differential expansion of cortical areas in simian primates. *Journal of Neuroscience, 33*(38), 15120–15125.

Coqueugniot, H., Hublin, J. J., Veillon, F., Houet, F., & Jacob, T. (2004). Early brain growth in *Homo erectus* and implications for cognitive ability. *Nature, 431*(7006), 299–302.

Csibra, G., & Gergely, G. (2009). Natural pedagogy. *Trends in Cognitive Sciences, 13*(4), 148–153.

D'Errico, F., & Banks, W. E. (2015). The archaeology of teaching: A conceptual framework. *Cambridge Archaeological Journal, 25*(4), 859–866.

Dehaene-Lambertz, G., Dehaene, S., & Hertz-Pannier, L. (2002). Functional neuroimaging of speech perception in infants. *Science, 298*(5600), 2013–2015.

Dehaene-Lambertz, G., Hertz-Pannier, L., Dubois, J., Meriaux, S., Roche, A., Sigman, M., & Dehaene, S. (2006). Functional organization of perisylvian activation during presentation of sentences in preverbal infants. *Proceedings of the National Academy of Sciences of the United States of America, 103*(38), 14240–14245.

Dehaene-Lambertz, G., Montavont, A., Jobert, A., Allirol, L., Dubois, J., Hertz-Pannier, L., & Dehaene, S. (2010). Language or music, mother or Mozart? Structural and environmental influences on infants' language networks. *Brain and Language, 114*(2), 53–65.

Dehaene, S., & Naccache, L. (2001). Towards a cognitive neuroscience of consciousness: Basic evidence and a workspace framework. *Cognition, 79*(1–2), 1–37.

DeSilva, J., & Lesnik, J. (2006). Chimpanzee neonatal brain size: Implications for brain growth in *Homo erectus*. *Journal of Human Evolution, 51*(2), 207–212.

Ekramnia, M., & Dehaene-Lambertz, G. (2019). Naming is more than creating an association: Four-month-olds create equivalence relation between words and categories of objects. Manuscript in preparation.

Emberson, L. L., Richards, J. E., & Aslin, R. N. (2015). Top-down modulation in the infant brain: Learning-induced expectations rapidly affect the sensory cortex at 6 months. *Proceedings of the National Academy of Sciences of the United States of America, 112*(31), 9585–9590.

Feigenson, L., & Halberda, J. (2008). Conceptual knowledge increases infants' memory capacity. *Proceedings of the National Academy of Sciences of the United States of America, 105*(29), 9926–9930.

Ferguson, B., & Waxman, S. R. (2016). What the [beep]? Six-month-olds link novel communicative signals to meaning. *Cognition, 146,* 185–189.

Ferry, A. L., Hespos, S. J., & Waxman, S. R. (2010). Categorization in 3- and 4-month-old infants: An advantage of words over tones. *Child Development, 81*(2), 472–479.

Ferry, A. L., Hespos, S. J., & Waxman, S. R. (2013). Nonhuman primate vocalizations support categorization in very young human infants. *Proceedings of the National Academy of Sciences of the United States of America, 110*(38), 15231–15235.

Friedrich, M., & Friederici, A. D. (2011). Word learning in 6-month-olds: Fast encoding-weak retention. *Journal of Cognitive Neuroscience, 23*(11), 3228–3240.

Friedrich, M., & Friederici, A. D. (2017). The origins of word learning: Brain responses of 3-month-olds indicate their rapid association of objects and words. *Developmental Science, 20*(2), e12357.

Friedrich, M., Wilhelm, I., Born, J., & Friederici, A. D. (2015). Generalization of word meanings during infant sleep. *Nature Communications, 6,* 6004.

Friedrich, M., Wilhelm, I., Molle, M., Born, J., & Friederici, A. D. (2017). The sleeping infant brain anticipates development. *Current Biology, 27*(15), 2374–2380.e2373.

Fulkerson, A. L., & Waxman, S. R. (2007). Words (but not tones) facilitate object categorization: Evidence from 6- and 12-month-olds. *Cognition, 105*(1), 218–228.

Gogate, L. J. (2010). Learning of syllable-object relations by preverbal infants: The role of temporal synchrony and syllable distinctiveness. *Journal of Experimental Child Psychology, 105*(3), 178–197.

Gogate, L. J., Prince, C. G., & Matatyaho, D. J. (2009). Two-month-old infants' sensitivity to changes in arbitrary syllable-object pairings: The role of temporal synchrony. *Journal of Experimental Psychology: Human Perception and Performance, 35*(2), 508–519.

Gunz, P., Neubauer, S., Maureille, B., & Hublin, J. J. (2010). Brain development after birth differs between Neanderthals and modern humans. *Current Biology, 20*(21), R921–922.

Hermer-Vazquez, L., Spelke, E. S., & Katsnelson, A. S. (1999). Sources of flexibility in human cognition: Dual-task studies of space and language. *Cognitive Psychology, 39*(1), 3–36.

Kabdebon, C., & Dehaene-Lambertz, G. (2019). Symbolic labeling in 5-month-old human infants. *Proceedings of the National Academy of Sciences of the United States of America, 116*(12), 5805–5810.

Kojima, T. (1984). Generalization between productive use and receptive discrimination of names in an artificial visual language by a chimpanzee. *International Journal of Primatology, 5*(2), 161–182.

Kouider, S., Long, B., Le Stanc, L., Charron, S., Fievet, A.-C., Barbosa, L. S., & Gelskov, S. V. (2015). Neural dynamics of prediction and surprise in infants. *Nature Communications, 6,* 8537.

Kouider, S., Stahlhut, C., Gelskov, S. V., Barbosa, L. S., Dutat, M., de Gardelle, V., … Dehaene-Lambertz, G. (2013). A neural marker of perceptual consciousness in infants. *Science, 340*(6130), 376–380.

Livingstone, M. S., Pettine, W. W., Srihasam, K., Moore, B., Morocz, I. A., & Lee, D. (2014). Symbol addition by monkeys provides evidence for normalized quantity coding. *Proceedings of the National Academy of Sciences of the United States of America, 111*(18), 6822–6827.

Marno, H., Farroni, T., Vidal Dos Santos, Y., Ekramnia, M., Nespor, M., & Mehler, J. (2015). Can you see what I am talking about? Human speech triggers referential expectation in four-month-old infants. *Scientific Reports, 5*, 13594.

Martin, A., Onishi, K. H., & Vouloumanos, A. (2012). Understanding the abstract role of speech in communication at 12 months. *Cognition, 123*(1), 50-60.

Medam, T., Marzouki, Y., Montant, M., & Fagot, J. (2016). Categorization does not promote symmetry in Guinea baboons (*Papio papio*). *Animal Cognition, 19*(5), 987–998.

Mesulam, M. M. (1998). From sensation to cognition. *Brain, 121,* 1013–1052.

Nazzi, T., & Bertoncini, J. (2003). Before and after the vocabulary spurt: Two modes of word acquisition? *Developmental Science, 6*(2), 136–142.

Neubauer, S., Gunz, P., & Hublin, J. J. (2010). Endocranial shape changes during growth in chimpanzees and humans: A morphometric analysis of unique and shared aspects. *Journal of Human Evolution, 59*(5), 555–566.

Neubauer, S., Hublin, J. J., & Gunz, P. (2018). The evolution of modern human brain shape. *Science Advances, 4*(1), eaao5961.

Neubert, F. X., Mars, R. B., Thomas, A. G., Sallet, J., & Rushworth, M. F. (2014). Comparison of human ventral frontal cortex areas for cognitive control and language with areas in monkey frontal cortex. *Neuron, 81*(3), 700–713.

Nieder, A. (2009). Prefrontal cortex and the evolution of symbolic reference. *Current Opinion in Neurobiology, 19*(1), 99–108.

Perszyk, D. R., & Waxman, S. R. (2019). Infants' advances in speech perception shape their earliest links between language and cognition. *Scientific Reports, 9*(1), 3293.

Price, D. J., Kennedy, H., Dehay, C., Zhou, L., Mercier, M., Jossin, Y., … Molnar, Z. (2006). The development of cortical connections. *European Journal of Neuroscience, 23*(4), 910–920.

Sakai, T., Hirata, S., Fuwa, K., Sugama, K., Kusunoki, K., Makishima, H., … Takeshita, H. (2012). Fetal brain development in chimpanzees versus humans. *Current Biology, 22*(18), R791–792.

Sakai, T., Mikami, A., Tomonaga, M., Matsui, M., Suzuki, J., Hamada, Y., … Matsuzawa, T. (2011). Differential prefrontal white matter development in chimpanzees and humans. *Current Biology, 21*(16), 1397–1402.

Srihasam, K., Mandeville, J. B., Morocz, I. A., Sullivan, K. J., & Livingstone, M. S. (2012). Behavioral and anatomical consequences of early versus late symbol training in macaques. *Neuron, 73*(3), 608–619.

Tincoff, R., & Jusczyk, P. W. (1999). Some beginnings of word comprehension in 6-month-olds. *Psychological Science, 10*(2), 172–175.

Tincoff, R., & Jusczyk, P. W. (2012). Six-month-olds comprehend words that refer to parts of the body. *Infancy, 17*(4), 432–444.

Vouloumanos, A., Martin, A., & Onishi, K. H. (2014). Do 6-month-olds understand that speech can communicate? *Developmental Science, 17*(6), 872–879.

Wang, L., Uhrig, L., Jarraya, B., & Dehaene, S. (2015). Representation of numerical and sequential patterns in macaque and human brains. *Current Biology, 25*(15), 1966–1974.

Waxman, S. R., & Markow, D. B. (1995). Words as invitations to form categories: Evidence from 12- to 13-month-old infants. *Cognitive Psychology, 29*, 257–302.

Xu, F. (2002). The role of language in acquiring object kind concepts in infancy. *Cognition, 85*(3), 223–250.

Xu, F., & Carey, S. (1996). Infants' metaphysics: The case of numerical identity. *Cognitive Psychology, 30*(2), 111–153.