A review of behavioural and brain development in the early years: the “toolkit” for later book-related skills

Saloni Krishnan and Mark H Johnson

18th July 2014

Table of Contents

Rationale for this review

This review was commissioned to Birkbeck, University of London by Booktrust in February 2014. Booktrust is a reading charity that changes lives through books. Booktrust gives millions of books to children of all ages through both universal and targeted programmes. They also offer resources and advice to families and professionals (including librarians, early years practitioners, health visitors and teachers).

Booktrust runs several programmes for children in the early years. Bookstart provides free book packs for every baby and pre-school child in England, Wales and Northern Ireland with guidance materials to support parents and carers to read every day with their child. In England, the Bookstart Baby pack is gifted to babies aged 0-12 months via health partners, and the Bookstart Treasure pack is gifted to children aged 3-4 years in early years settings. Booktrust also provide specially designed packs for blind and deaf children (Booktouch and Bookshine) and Bookstart Star for children that have a condition or disability that impacts on their fine motor skills. Finally, Bookstart Corner is a targeted home-based intervention, which supports families with the greatest need, encouraging them to develop a love of books, stories and rhymes.

Booktrust commissioned this review, outlining the evidence on brain development in first three years of life, to help to inform the age at which they recommend as being the optimum time for parents/carers to start sharing books, stories and rhymes with their children. This review is expected to help inform the development of Booktrust's programmes and work in the future by exploring what the research evidence suggests for the timing and nature of literacy interventions. This review includes a general overview of brain development in utero and during the first three years of life, before focusing on the specific areas of brain development associated with language, literacy, memory etc., and how the development of these areas can be affected by environmental factors. It also explores the development of sight and hearing– both in utero and from birth - and the implications this has for learning at different stages of development.

Mission statement for this review

Relating the growth of the brain to developmental changes in action, perceptual, and thinking abilities during the early years of human life presents a considerable scientific challenge. We review the current state of knowledge in this field with particular reference to book-related skills. Here, over four sections, we will:

I. Set out the principles of early brain development
II. Discuss the early development of perceptual and cognitive (thinking) systems that are relevant to book-related skills
III. Consider environments that affect the development of perceptual and cognitive systems related to reading
IV. Consider how we can promote or optimise book-related skills

SECTION I: The principles of early brain development

In this section, we introduce the basic principles of brain development. We briefly overview structures of the human brain and highlight those regions relevant to this review. Key processes in brain development before birth are described, including neuronal formation, migration, and myelination. By birth, the brain is functionally active – we discuss how we know this and also show that learning can occur prior to birth. We then turn to the changes in connections in the brain over development. These changes include simple increasing or 'additive' trends as well as the classic 'rise and fall' patterns characteristic of some aspects of human brain development.

The protracted period of human brain development after birth (see Box 1) represents an opportunity to understand how the environment shapes the brain. Concepts such as sensitive periods and "plasticity" during development are discussed in order to better understand how the environment plays a role in brain development. Finally, we consider how certain brain regions and networks may "specialise" to deal with particular types of information from the environment, and review our current understanding about how this specialisation occurs over development.

The human brain: an introduction

The human brain is arguably the most important organ of our body and is responsible for almost everything we do, whether it's dreaming, playing sports or learning new information. It weighs just over a kilogram and contains over 100 billion nerve cells. The brain uses 20% of the energy generated by the body, even when we are apparently "resting" [1]. Here, we introduce some of the terms we will use throughout the report.

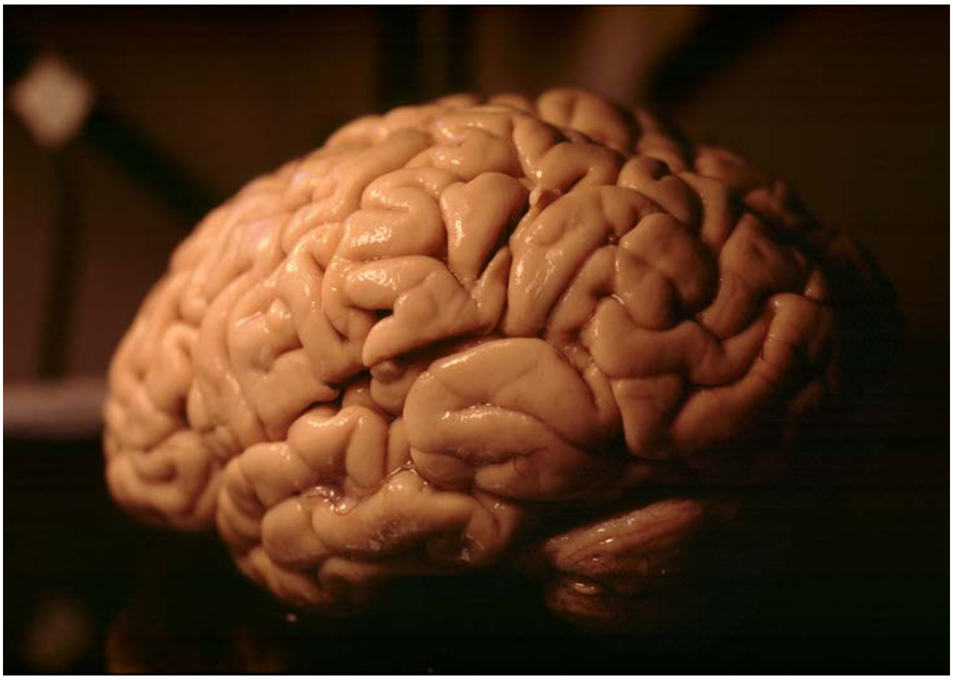


***Figure 1**. Side view of the human brain (source: Wellcome Images)*

When people look at pictures of the brain (see Figure 1), the part that resembles a large walnut is usually what is thought of as “the brain”. However, beneath this visible part of the brain (forebrain) are the so-called hindbrain and midbrain structures (these can be seen more clearly in Figure 2, which shows a slice through the centre of the brain). The forebrain consists of two hemispheres (left and right) that are bridged by a large white bundle of connections. The midbrain consists of structures found on the upper part of the brainstem - these are important for reflex actions and may be involved in reward and mood. The hindbrain consists of the cerebellum (or “little brain”). The cerebellum can be seen in the inset of Figure 2, just underneath the forebrain.

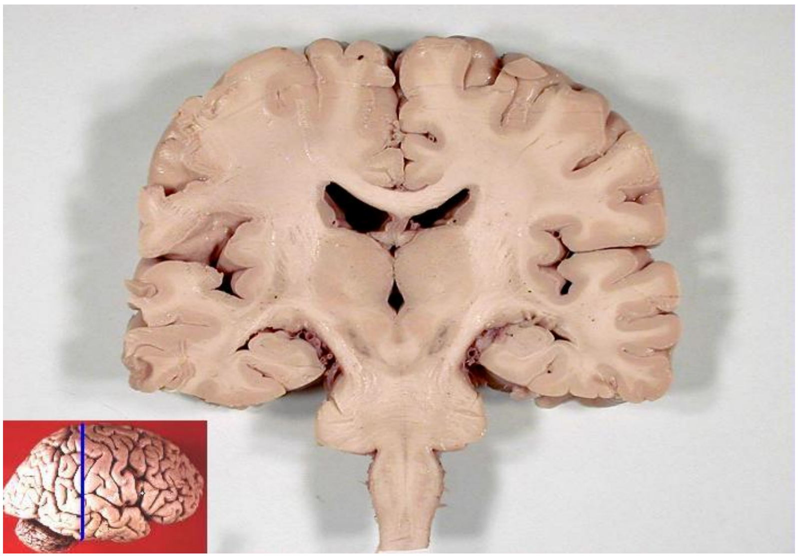


Figure 2.*Coronal section of the brain. The inset shows where the section was made.*
Photo credit: John A Beal (Louisiana State University) via Wikimedia Commons

The outer layer of the forebrain is known as the cortex (see Figure 2). The cortex is often called “grey matter” because the number of cell bodies and processes of the neurons packed into this layer give it a darker appearance. However, the cortex is not the only place grey matter is found. There are also grey matter bundles underneath the cortex (the “subcortex”). Underneath the cortex, we can see the “white matter” of the brain. White matter generally refers to bundles of connecting fibres covered in a fatty substance called myelin (see page 8).

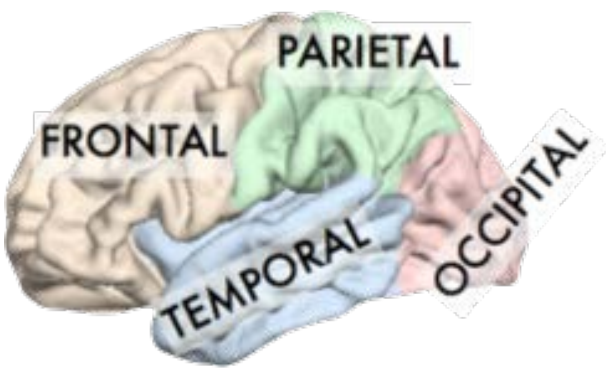


Figure 3. *Lobes of the human brain*

The cortex has a central role in processing the sensory information from the world around us, as well as mental processes such as attention, memory, and decision-making. It is an intricately folded sheet of 2-4mm thickness and with an area of about 2400 cm^2. It is made up of six layers that can vary in their thickness across different regions. In adults, different parts of the cortex (see Figure 3) are associated with varying functions. The *occipital* cortex is important for processing what we see through our eyes. Parts of the *temporal* cortex are specialised for processing sounds as well as social information about the appearance and actions of other humans. The *parietal* cortex is important for touch and representing space. Finally, the *frontal* cortex is important for motor behaviour as well as for planning, executing behaviour and making decisions.

While each of these regions is thought to be associated with different functions, these regions do not function all by themselves. Neuroscientists believe that it is differential patterns of activity across multiple regions that are important for performing everyday tasks. Nowadays, scientists are trying to characterise the network of regions associated with performing a task. Let us take the simple example of brain activity involved in naming a picture. For this task, frontal, temporal and occipital cortex regions are all 'activated'. However, we can make an informed guess that occipital regions are activated as we are *looking* at a picture, temporal regions are activated as we *retrieve sounds* associated with the name of the picture, and frontal regions are activated as we *move our mouths* to say the name of the picture.

The brain is made up of two kinds of cells, neurons and supporting cells. The basic working unit of the brain is the neuron (shown in Figure 4). Neurons come in many different shapes and sizes, which may reflect their precise function. They receive electrical signals via branched projections called a dendritic tree, and send out signals through nerve fibres called axons. Neurons communicate with each other via chemical messengers called neurotransmitters, which act somewhat like on/off switches for the next neuron. Neurons are less common than supporting cells in the brain.

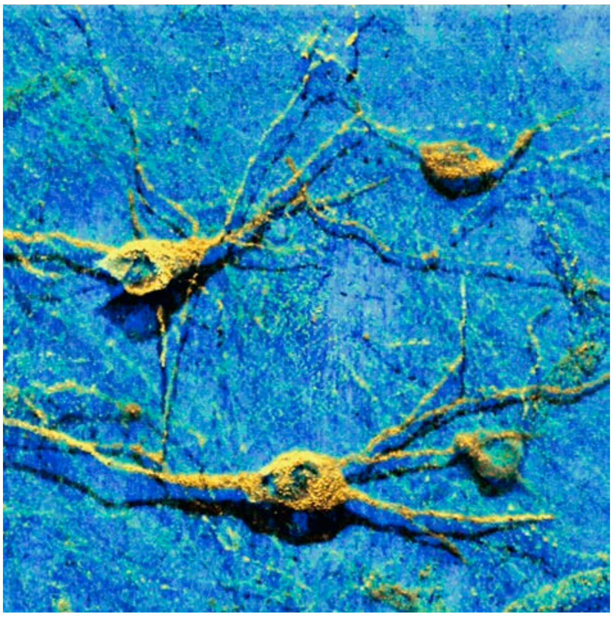


Figure 4. *Neurons in the human brain (source: Wellcome Images)*

Brain development in utero

Neurons are 'born' during a sequence of events involved in the prenatal development of the human brain. The fertilised egg initially divides to form a cluster of cells. This cluster then differentiates into a three-layered structure; each layer of which gives rise to different organ systems. The outermost layer is responsible for the development of the nervous system and brain and neurons are born as part of this process. After young neurons are born, they travel or migrate to the region where they are eventually located in the mature brain. Once a neuron has migrated to its final location, it develops connections with other neurons at both ends – on one end, it forms a dendritic tree and integrates into the grey matter and at the other end, its axon forms part of the white matter (Appendix 1 details the intricate process of early brain development).

After the underlying white matter structure has been formed by the axons, the brain becomes much more efficient at transmitting signals due to the process of myelination. In this process, nerve fibres become covered by a fatty sheath called 'myelin' that allows faster and cleaner transmission of nerve impulses. This is akin to coating an electrical wire to make signals transmit faster. By the time the foetus is 37-40 weeks, myelin can already be detected in some subcortical structures. Myelination continues into the second decade of life. Cortical association areas (areas that serve a secondary function rather than processing basic sensory or motor signals) are the last to be myelinated. There has been much speculation linking myelination to advances in behavioural and cognitive development[2]. However, while myelination greatly increases the speed and fidelity of transmission of nerve impulses (by a factor of 100), under-myelinated connections are still capable of transmitting signals, and some connections never myelinate (also see later section on key patterns on neural change after birth, page 10).

The brain is functionally active at birth

By the time of birth in humans, the vast majority of neurons have been born, migrated to their final locations, and have differentiated into recognisable types. The main lobes of cortex are also developed and the brain is functionally active[3].

There is some evidence to suggest that the brain is ready to learn even before the baby is born. As infants can hear sounds in utero, most studies have used sound to assess learning. For example, in one study, babies were played the theme song of a popular TV soap opera both during pregnancy, as well as shortly after birth. Changes in movements of the foetus (and then newborns) were found in response to this familiar tune, an effect that lasted for at least 3 weeks after birth[4]. Foetal learning has also been demonstrated using familiar nursery rhymes read by mothers [5]. More recently, researchers have measured how familiar native and non-native vowel sounds were to newborns using number of sucks on a pacifier as the measure. This showed that newborns (7-7.5 hours after birth) could differentiate between vowel sounds from their language and those from a non-native language [6], suggesting that the sound that a baby hears in-utero shapes their listening preferences after birth.

While this evidence suggests that the brain is functionally active before birth, until recently we have not been able to directly examine brain activity during infancy. A promising new window into functional brain development involves scanning the brain during rest (while a participant is not engaged in any particular task). Functional networks of different regions of the brain can then be extracted from these scans and are thought to reflect averages of sensory and task driven activation patterns over a prolonged period. In adults, these functional networks share regions in common with task-activated networks, such as those associated with action, and vision and sound processing. Recent work shows that functional brain networks begin to emerge in the third trimester of pregnancy. When pre-term infants were scanned at thirty weeks the functional networks were barely recognisable, but by the time of birth they resembled adult resting-state networks[7]. In full-term infants, studies have detected functional networks involving the primary central and motor areas, prefrontal cortex and cerebellum [8]. However, while the functional networks in infancy resemble those seen in adults, they are not yet complete or stable, further suggesting that the full network architecture of the brain emerges over childhood[9,10].

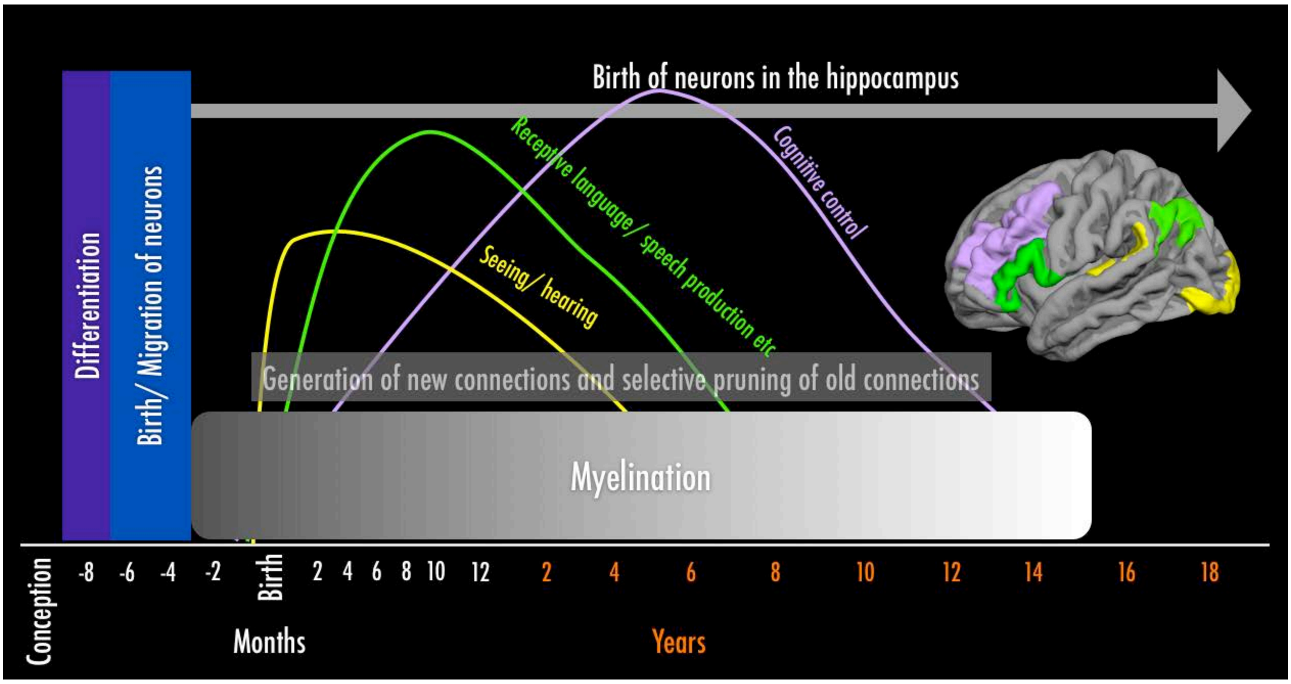


***Figure 5**. This graph illustrates the key prenatal and postnatal events in brain development (Adapted from [11,12]). The classic "rise and fall" pattern described in-text is illustrated over different regions of cortex via corresponding colours, as are additive processes like myelination and hippocampal neurogenesis. For illustrative purposes, labels on the curve approximate the functions of the brain regions shown in the same colour.*

Key patterns of neural change after birth

Between birth and adulthood, there is a large 3-to-4-fold increase in the total volume of the brain. The increase in volume cannot be explained by the addition of neurons as the vast majority are in place at birth. However, there is a dramatic increase in size and complexity of the dendritic tree (see page 7) of most neurons after birth.

Microscopic study of post-mortem brains[13,14] shows that there is a steady rise in the quantity of connections made by neurons in different regions of the cortex over the first years of life. While an increase in these connections begins around birth in humans for all cortical areas studied to date, the most rapid bursts of increasing connections, and the final peak, occurs at different ages in different areas. For example, in the occipital cortex, there is a rapid burst at 3 to 4 months, and the maximum number (around 150% of adult level) is reached between 4 and 12 months. In contrast, while the generation of these connections starts at the same time in the frontal cortex, the number of connections increases much more slowly and does not reach its peak until mid-childhood (approximately 6 years of age). Once the peak is reached, we observe a fall in the number of connections. While the extent and reach of a cell's dendritic tree may increase dramatically, precisely which neurons it connects to becomes more selective. This increased selectivity is achieved through *pruning* out those connections that have been largely unused resulting in a fall in the number of connections.

In contrast to the rise and fall pattern [15] described above, other aspects of postnatal human brain development are additive, such as myelination of white matter (discussed in prenatal development), and therefore show a steady increase with development. Another additive process[11] is the gradual addition (or replacement) of neurons in the hippocampus/ striatum (structures that are thought to be involved in memory and learning). Figure 5 depicts the key prenatal and postnatal events in brain development.

While the developments in the brain discussed so far concern aspects of the structure of the brain, it is important to note that there are also developmental changes in the chemical messengers (neurotransmitters) of the brain[16]. Neurons can be thought of as sitting within a bath of different chemical substances that enhance or inhibit their activity. A number of these neurotransmitters also show the rise and fall developmental pattern. The distinctive "rise and fall" developmental sequence is therefore seen in not only in terms of structure of the brain (its wiring patterns), but also in some of the chemical messengers supporting neural function [15].

Sensitive periods and brain plasticity

Periods during which parts of the brain are maximally responsive to experience, or influenced by the environment, are known as *sensitive periods* [17]. During these sensitive periods, the brain is considered to be at its most flexible, or “plastic”. Sensitive periods are a feature of development across species. For example, songbirds only have a certain window of time to learn their song[18]. Not exposing them to a tutor song during this period means that they will not be able to produce it themselves. In humans, sensitive periods were originally invoked to explain differences between learning your native tongue versus second language learning. When learning conditions are equalised, adults and children can show similar abilities to learn language, but later learning of language is rarely achieved without an accent[19]. Other evidence for sensitive periods comes from studies of basic perceptual systems such as vision or audition (see Sections II and III). Here, we consider in more detail what sensitive periods actually are.

As development unfolds, increasingly more complex types of cells and specialised structures emerge. The development of biological structures, such as the brain and its constituent parts is often considered as a process of *restriction of fate* in which cells become increasingly differentiated and specialised for certain functions[20]. For example, stem cells are examples of cells that still have many different options available for their later forms. Experiments show that if you transpose the location of a group of cells within the developing embryo they will often develop to form a different structure from that which they would have done if left in their original location.

Plasticity is the flip side of the coin to "restriction of fate". In development, we can simply view plasticity as the result of a brain region's structure or function not yet being fully committed or tuned. By this view, the mechanisms of plasticity remain the same throughout the lifespan. However, the expression of plasticity is more limited in adulthood because most aspects of brain structure and function have already become specialised and stabilised and thus there is less scope for further change [20,21].

Recent studies have enhanced our understanding of the cellular and behavioural processes associated with sensitive periods. Experiments show that plasticity can be prolonged beyond the typical end of the relevant sensitive period simply by changing the type of experience [22,23]. For example, targeted video game practice on visual perception tasks led to long-lasting improvement in performance for patients with amblyopia (who have a loss of vision in a 'good' eye due to early visual deprivation). While this research is in its early days, it points to the way to how a better understanding of sensitive periods might be applied to child development.

Functional specialisation

Over time, some parts of the brain become specialised for certain activities (e.g., a region originally responsive to a wide variety of visual objects may come to confine its processing exclusively to upright human faces[24,25]). The activity level of a given cortical region is determined by the activity in the regions connected with the region as well as the pattern of connectivity. During postnatal development, changes in the functions of cortical regions occur as they interact and compete with each other to acquire their roles. The onset of new behaviour during infancy will therefore be associated with changes in network activity over several regions. For example, a region in between the temporal and occipital lobe in adult brain is more responsive to written words relative to other complex visual patterns. This region lies in between regions specialised for object recognition and those specialised in retrieving sound information. Activation of this region becomes more precise with increased experience of reading, showing that there is increasing fine-tuning or specialisation occurring in this neural region[26]. In Box 2, we also discuss another kind of specialisation that has interested many neuroscientists: the balance between the left and the right hemispheres.

While experiments have provided evidence for the increasing specialisation of individual parts of cortex during postnatal development, it is clear that the next step is to understand how networks involving different regions, each with their own different specialisations, emerge.

SECTION II: Early development of sensory and cognitive systems relevant to the enjoyment of books, rhymes and songs

In this section, we discuss the typical development of sensory skills such as hearing and vision and the role they play in learning to read. Our focus here is on how children build their language systems and start to make sense of the visual world around them. We also highlight the importance of social support for the young child to learn about the world around them, and on how social behaviour is important for language and literacy.

A. Early hearing and language development

For later reading proficiency, children need to have good sound processing systems as well as vocabulary skills. They can then map this knowledge onto the objects and the symbols that they can recognise and remember. Here, we discuss how children learn the sounds and words of their native language.

A.1. Laying down a "sound" foundation

Infants hear the sounds of their native language prior to birth (but sound information is muffled due to the presence of amniotic fluid and the mother's belly) [27] and they can recognise what vowels in their native language should sound like[6]. Even a few hours after birth, infants have a preference for their mother's voice and can distinguish the rhythm of their native language (for example, the rhythm or prosody of Japanese as compared to English). However, newborns don't just like human speech, they show an equal preference for sounds similar to human speech (similar to their preference for face-like images, see box 3). However, by three months of age, infants have developed a clear preference for human speech even over closely related vocal sounds such as monkey calls. This suggests that experience of hearing speech and language plays an important role in tuning this perceptual system [28,29].

As development progresses, broad listening biases are shaped by the sounds that are necessary for the language the infant will speak. In this regard, infants' listening behaviour *mimics* the classic rise and fall pattern described in early brain development. Initially, infants can discriminate between sounds of most languages - for example, 6-8-month-old infants discriminate between two Hindi "da" sounds that native English adult speakers do not (as it is not relevant within their language). 10-12-month-old infants raised in an English-speaking environment lose the ability to discriminate between the two Hindi sounds, while Hindi exposed infants do not. It has been suggested that children actively learn which distinctions to keep processing, based on extracting statistical information about the distribution of sounds in their native language. This "tuning in" or re-organization of perceptual systems is considered useful for later learning as children focus on what is relevant for their particular communication skills. It is important to note that some phonetic categories (the boundaries of speech sounds in a language) can be regained even in adulthood [23]. However, learning in adulthood seems to involve more effort, perhaps as resources have already been committed to one set of biases [30].

The sound processing systems (learning which sounds are relevant as well as how they combine within one's native language) discussed here are very important for later literacy. In fact, such fine knowledge of sounds in an individual's native language is the best predictor of later reading skills. Children are aware of some elements of sound structure in their language even before starting school (for a further breakdown, see the line on phonological processing in Figure 6 [31]). As early as three years of age, children show awareness of rhyme and alliteration (as in "Peppa Pig"). Three-year-olds may become familiar with finer details of sound structure in their language through nursery rhymes [32]. In the rhyme "Jack and Jill went down the hill", to understand that 'Jill and 'hill' rhyme, children must learn that the two words have some sounds ("ill") in common, and that the common part is a segment of both words. Further, they can learn that the addition of a single sound to this common segment changes the meaning of the word. Indeed, children's recitation of rhymes at age 3 has been found to predict the development of the understanding of such details of sound structure even when controlling for their IQ and family background [33] (also see Box 4 for how rhymes and songs might influence auditory preferences).

Building flexible and detailed knowledge of the sound units in one's language, as well as how they combine, is important for later literacy [34], as it is these units that will be mapped onto visual symbols during reading. However, this relationship is a two-way street as reading itself builds this fine knowledge of sound [35].

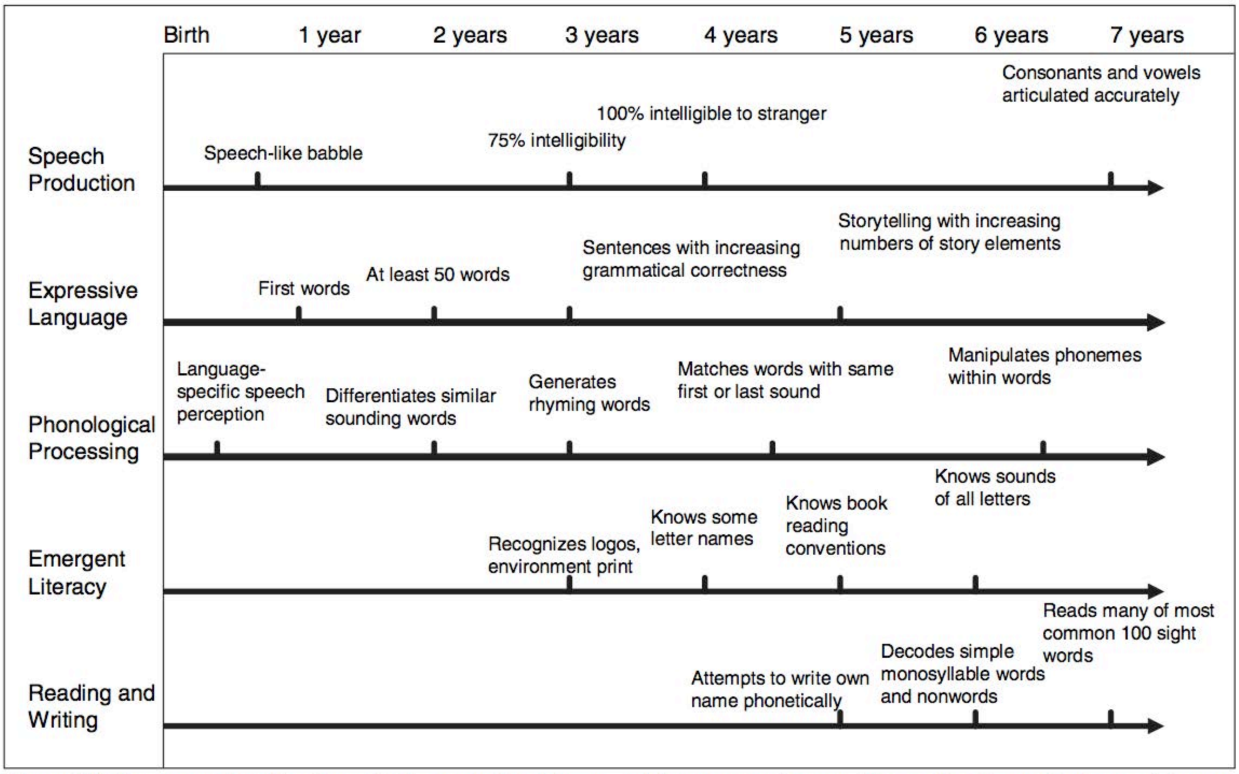


Figure 1) *Milestones on the path to literacy in the preschool period, extracted from a range of sources. They are based on a school entry of six years of age and adequate learning opportunities and experiences. Variations from this pattern should be seen as the starting point for a more detailed analysis, and do not in themselves allow for diagnosis. Children exposed to several languages at home or (pre)school may show different profiles*

***Figure 6** depicts milestones on the path to literacy. Figure sourced from Rvachew and Savage (2006) [31] and was originally published in Paediatrics and Child Health 2006;11(9):589-593.*

A.2. How do babies learn words?

An early challenge for infants is finding the words in their language. This is best illustrated by an adult's experience when listening to a foreign language. A phrase like "yeh-kursi-he" ("this is a chair" in Hindi) is continuous, and even if the listener knows the speaker is referring to a chair it is hard to separate out which part of the sound stream specifically refers to chair (in this case, "kursi"). With only a few minutes exposure to a language, infants can work out the likelihood that pairs of sounds occur within the language concerned. This means that they use probability to understand that "hk" or "ih" are less likely to be a part of words and more likely to signal boundaries between words in the phrase. This ability is referred to as "statistical learning" [36]. Eight-month-old infants begin to extract the words (and as they grow older and more familiar with the words in their language, the grammatical structure) of their native language [36]. Furthermore, as they become familiar with the sounds that occur in their language and the frequency with which they occur, they extract phrases and elements of sentence structure.

Words spoken out of the context of a sentence must be linked to the object they refer to ("the referent") in order to build a vocabulary. Children seem to learn associations between a word and its referent using a range of different strategies. For example, children follow the eyes of others (gaze cues) and use gestures like pointing. Some authors have suggested that infants also use cognitive strategies such as "mutual exclusivity" (for example, if we already know what an orange is we can conclude by looking at a new object that the spoken word "orange" does not refer to that object). It is important to note that children younger than 17-months struggle to map words that are extremely close in phonological (sound) space to differing referents (for example, "bih" vs "dih"). In this example, the sounds "b" and "d" differ by only one feature, but the feature they differ by can differentiate words. This suggests that making new word-object associations is particularly difficult when the sound information provided is very similar - this may be due to the increased effort required to detect and process the difference [37]. The effort that is required for word learning can be reduced in a variety of ways, e.g. by making the sounds of words more distinguishable. While learning the words for objects can be very quick, an emerging body of evidence suggests that retaining these associations in memory and being able to produce these novel words follows a much longer developmental trajectory [38,39].

Large studies involving parental questionnaires show that children begin to understand what many words refer to (comprehension) around 9-10 months of age [40]. Word production typically starts a few weeks later (see Figure 6 for typical milestones in speech production and expressive language [31]). Children's early productions tend to involve the names of objects, although some children do use holophrases (for example, the word "food" to indicate "give me food"). This early period of expressive language development is characterised by a great deal of individual variability [40]. For example, between the ages of 16-20 months, infants dramatically add to their vocabularies, prompting some researchers to call this phase of development the "vocabulary burst". Interestingly, around 16 months of age, typically developing children in the lowest one percent of language development skills produce about 10 words. However, children in the highest percentile produce about 180 words. This variation is typical as all these children go on to have typical language skills as adults. Yet, such differences are important to keep in mind when trying to understand developmental differences in language [41].

B. Early visual development

Children start out by learning to recognise and differentiate objects in our complex visual world. Later in development, they will learn to distinguish finer visual features associated with letters. Here, we focus on the developments in children's visual perception, starting from the early differentiation of objects from their background visual scenes and how they start to use their visual experience to act on objects.

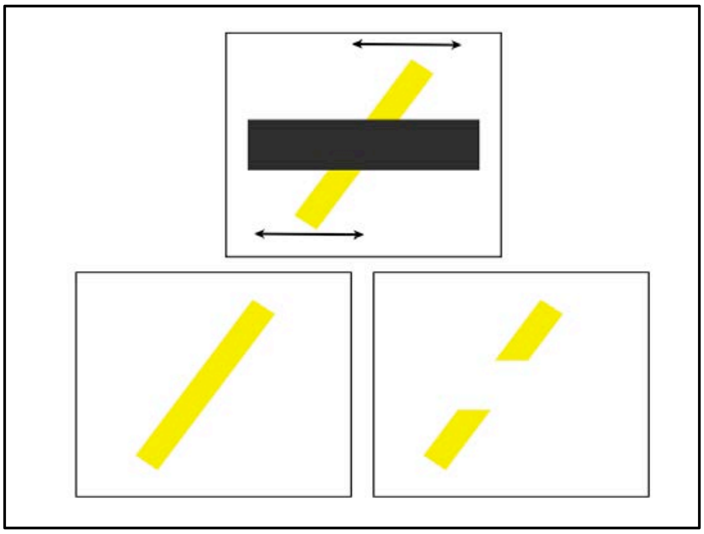
Although the structure of the eye, lens, and eye muscles are mainly complete by the third trimester in-utero, they are not fully developed by birth. Changes in these structures, as well as changes at the level of the brain itself, place limitations on children's vision. Children's visual acuity is relatively poor in the first few months of life. In comparison to adults who are able to detect differences of about 1% visual contrasts, newborns require contrasts of around 30-40% before they can detect them (simple black and white patterns are very high contrast and approach 100%)[42]. Further, infants become better at focussing on objects from two months of age, whereas appreciation of depth cues (and therefore distance) from pictures only emerges by around five months of age[42].

Until recently, it was unclear whether it was the limitations imposed by changes in the eye, or by the changes in visual pathways in the brain, that limited visual processing early in life [43]. Analyses in which the form and structure of photoreceptors in the eyes of newborns were compared to adults have revealed that the age differences in the resolution of visual processing observed are much greater than predicted on the basis of the eye limitations alone [44]. This shows that *brain development has an important role to play in the development of vision* [44]. While infants respond to visual input in some of the same brain regions that are specialised for vision in adults[43], there are clearly considerable brain changes that take place over development (also see Section III for the role of experience of the environment in driving these changes).

B.1. How do babies learn to recognise an object?

As adults, we take the existence of objects for granted. For example, when we see a photograph of a family on holiday we can differentiate between the members of the family, guess where the photograph might have been taken based on recognisable landmarks, what objects the children might be holding and so on. However, the basic visual elements of this photograph are simply overlapping and adjacent surfaces comprising different colours, shapes, and visual textures. Over development, individuals have to learn to be able to separate such visual scenes into meaningful components, in much the same way as they need to extract words from a stream of sounds. This is particularly important for their understanding of the visual world around them, because they would otherwise experience it as a series of fleeting surfaces, instead of as objects and people that move in coherent ways within structured landscapes [45].

The extent to which the infant brain acquires the ability to see objects as separate from their background through experience of visual scenes remains somewhat controversial. While newborns can see objects as being different from the surrounding background, their processing of these objects is more fragile and fragmented than that of adults [45]. A classic study illustrates this using so-called box-and-rod displays (see Figure 7). Babies are familiarised with a display of a moving slanted rod partially covered by a box in front. The perceived motion makes it look as though the rod is moving horizontally behind the box. Later, infants are shown a whole rod or a broken rod. The amount of time an infant looks at the 'new' object is used as an assessment of their understanding of object representations (see Figure 7). Newborns perceive the rod to be two parts (as in the rod shown on the right), but after four months of age they correctly identify it as being a single object that was previously partly obscured from view (rod on the left) [46]. It has been proposed that this is because newborns require a full range of different cues (including common motion, 3D depth cues, background texture, and alignment of object edges) for



detecting whole objects [47]. In contrast, adults and older infants need many fewer cues in order to perceive their visual world as composed of objects of different shapes and sizes, and at different distances.

Figure 7. *The box and rod display is shown in the top image. The two images on the bottom show what representations of the rod could look like when the box is removed.*

B.2. Acting on objects

The visual processing of objects is divided into two relatively separate systems ("what" and "where") in the adult brain. The "what" stream extends from the regions specialized for vision to the temporal lobe; the "where" route extends from the occipital cortex to the parietal lobe. The latter "where" route is important for planning and performing actions on objects, for example, reaching for and grasping an object. Studies indicate that activation in the "where" route involves tracking the motion of an object in space in terms of its location, for relative motion when the object moves away from or towards the viewer, as well as the size, general shape and orientation. These functions of the "where" stream are complementary to those of the "what" route. Regions in the "what" stream respond to the specific features of objects in a spatially invariant manner, allowing adults to recognise features of objects, scenes and individuals in a more enduring manner (i.e. regardless of their distance or location).

Integration of these two pathways has been found to be necessary before children could successfully reach for and grasp specific objects. In one experiment [48], infants watched as objects were presented on a stage before a screen came down to hide them from view. When the screen was lifted, the experimenters changed some details about the toy. Sometimes the surface features (colour, facial identity) of the toy were changed, sometimes the location was changed, and occasionally both were changed. Infants were found to be able to remember *either* the features or the location change, but not both. This indicated that infants could use the "what" and "where" pathways independently, but not together. Further, if the task involved objects that were the right size/ shape for infants to grasp, they would be more likely to activate the "where" pathway. However, if the object was too large or too far away, it was more likely to activate the "what" pathway.

The typical onset of attempts to reach for objects (with an open hand) is about four months of age. However, younger infants can be trained to control objects. In a novel study, this was accomplished by having infants wear little mittens covered in Velcro. The infants were then given toys that would stick to these mittens, which enabled them to lift objects by simply by swiping at them and making contact. When tested later without the gloves on, these infants showed increased hand-eye co-ordination and more mature grasping compared to infants who were not given this unusual early Velcro experience [49,50]. Once infants became more skilled at reaching and grasping, they were also more influenced by the size and relative distance of an object [51], suggesting better integration of the “what” and “where" pathways.

C. Early social development

Here, we focus on why social behaviour is important for language and literacy.

Infants direct a great deal of their attention to adults, not only for protection and nutrition, but also because they are usually the best and most reliable sources of information about other aspects of the world. In other words, babies need to learn *about* others, so that they can then learn *from* others. In fact, social behaviour shows considerable changes in the first years of life. Infants progress from understanding the cues adults use to direct the attention of others (such as directing eye gaze), to then sharing attention to objects with others, to then being able to direct others’ attention toward things of common interest [52].

As previously discussed, eight-to-nine-month-old infants can pick up information about the sound structure specific to their language within a few minutes of exposure (see ‘statistical learning’[36], page 13). Studies have shown that for this kind of learning to occur a live human speaker is not absolutely essential. However, English-speaking nine-month-old infants learnt a foreign language (Mandarin) much better when they had a live teacher compared to when they were exposed to televised teaching, or an audio presentation [53]. In the live teacher condition of this study, teachers read books and played with toys and used unscripted language. In the television/audio conditions, the same teachers were used, and the same statistical information about the language could be extracted from their speech [53]. The importance of social interaction has been observed even for speech production [54,55]. These effects could be due to increased attention and arousal elicited by the presence of another human. They could also be a result of the information gained during social interaction. For example, in a live situation, what a tutor looks at and points to might convey more complex and multi-sensory information about the world around the infant [56].

A social behaviour that appears particularly important for language and literacy is “joint attention”. This is when two individuals share a common focus of attention on an object of mutual interest[57]. The quantity and quality of joint or shared attention between children and their caregivers has also been linked to early communication abilities in the child[58]. When joint attention abilities emerge is a matter of debate and is linked to the specific conditions studies have been conducted in. In general, when a very simple visual scene is used, babies can follow adult’s direction of eye gaze to the left or the right as young as two-to-three months of age. However, babies only begin to look behind themselves when following another’s gaze after about twelve-eighteen months of age, suggesting that their original search space is limited. Babies start to try to direct the attention of adults at around nine months of age. Pointing is another way to signal what objects both individuals are interested in. It is believed that babies typically start to comprehend adult pointing at around ten months of age, and start pointing themselves soon after [59].

SECTION III: Environments that affect skills related to later literacy

In the following section, we consider how different sensory, social and cultural environments could influence development.

The effects of the environment

It has been known for some time that there are substantial effects of the environment in which an animal is raised on the patterns of connections and functional specialisations that develop within their brain. This has been demonstrated in studies where rats were either reared in cages with toys and other objects they could explore, caged with other rats but without toys, or caged alone and without toys[60]. The results were clear - only active experience with the toys allowed animals to extract appropriate information to deal with complex, appetitive tasks (finding food in a new maze-like spatial environment). Further, the numbers of connections in regions of their brain were quite different across rats reared in these different conditions. The rats raised with toys had about 2000 more connections per neuron than rats that were caged alone, with the rats who had other rats for company falling in between[60]. This suggests that a complex, rich and variable environment is important for the optimal development of brains. While experiments like this on humans would clearly be unethical, scientists have used a variety of naturally occurring environments to understand effects on human development. Here, we discuss the effects of bilingualism as well as those of more challenging sensory/social environments on children's brain and cognitive development.

Differing environments in development: challenging sensory environments

Changes in the sensory environment (for example, blindness from birth) can have consequences on visual and social behaviour[61]. Scientists have studied individuals who were partially blind for some period of time after birth due to being born with dense cataracts in both eyes. These cataracts were surgically reversed to allow clear vision within the first year of life. Despite this early intervention and after years of normal visual experience, there were life-long effects on several aspects of vision. While children with cataracts at birth recovered their sensitivity to low spatial frequencies (wide stripes at low contrast), they had difficulties in seeing the finest detail of images when they were tested at 7 years of age[62]. In addition, they were better at focusing on parts or features rather than the overall gist of an image. For example, in face processing tasks, they focused on the features of the face (such as eye shape) rather than how features fit together to form a face. They failed to notice differences in cues that signal changes in configuration, for instance, distance between the eyes[63].

Sighted children who are born to blind parents have a smaller but significant change in their visual environment, i.e. their parents do not provide them with the typical range of eye gaze cues (for a discussion of why these cues are important, see the section on early social development, page 18). However, this reduced experience of eye contact and gaze behaviour does not preclude sighted infants from developing typical processing of these stimuli and other social-communication skills[64]. Indeed, the need to switch between different types of communication strategy may actually enhance other general skills during development [64].

In Section I, we have discussed 'sensitive periods' in human development. Children born with hearing impairment have been used as an example to illustrate sensitive periods for spoken language in humans. Many of these children faced difficulties in learning spoken language even after their hearing ability was restored via hearing aids or cochlear implants in the preschool years. It was believed that this reflected the closing of the sensitive period for language, and that early intervention for hearing was crucial for successful spoken language learning. The closing of the sensitive period for language was thought to be solely related to the lack of early sound experience.

In addition, neural evidence suggested that the lack of early sound experience caused changes in both connections between different kinds of sensory inputs and plasticity of the brain regions associated with sound processing. Event related potentials are calculated by averaging multiple instances of electrical activity from the brain in response to a specific signal. In individuals who are deaf from birth, these measures suggest that areas of their auditory cortex are more sensitive to peripheral visual stimulation than is typical[65-67]. These results have been interpreted as a take-over of regions of cortex that are normally dedicated to the processing of sound by visual processing, due to the absence of hearing early in development. To prevent such a take-over, parents of children with hearing impairment were previously advised not to provide their children with visual language input.

However, these results need to be interpreted with some caution with respect to intervention. For deaf children raised in deaf families, language milestones are achieved at similar ages to those of hearing children (note that these milestones refer to sign language milestones in deaf families and spoken language milestones in hearing families) [68]. More recent findings and advice is that early exposure to language input by any means (including visual or sign language) is very important for later language outcomes.

Differing environments in development: challenging social environments

Analyses that estimate the relative genetic and environmental contribution to behaviour show that the environments children are exposed to influence reading ability [69]. Researchers have used socioeconomic differences to explore how the environment contributes to individual differences in phonological awareness (awareness of sound structure in words), as well as differences in the understanding and production of language (key skills that feed into reading ability). A seminal study [70] demonstrated that the difference in language experience for children whose families were on welfare as compared to those in 'professional' families was some 30 million words by 3 years of age (this number includes repetitions of the same words/ phrases and is only an estimate of the difference in exposure to speech). This study also looked at children growing up in "working class" families, whose language experience lay somewhere in between the other two groups.

Interestingly, the authors suggest that this is not entirely due to the complexity of parent's speech, which was fairly similar in all three groups. Here, we discuss some other reasons that might explain these linguistic differences across socioeconomic status. Greater experience with language can increase the rate of growth in receptive and expressive language [71]. One of the factors that characterised children accelerating from a low performing group to a high performing one was increased exposure to language via shared book reading activities (parents and children reading books together) [72]. Here, we focus on why such sharing of books might be particularly important.

It is tempting to assume that early exposure to print (via books) is the factor that influences children's later language and literacy abilities. However, in a study that measured 4-to-5-year-olds children's eye movements as they were read storybooks, children did not appear to pay much attention to the text [73]. Rather, they focused on the illustrations of the stories, even if these were just simple line drawings [73]. Such research emphasises the sharing of attention component of early book use, rather than the simple exposure of the child to printed text. Parent-child interaction during parent reading establishes a joint focus of attention between the child and the adult. It is likely that children's attention to book illustrations, in concert with the accompanying spoken language from their parent, enhances children's vocabulary. Some studies suggest that parental language is more complex during shared reading events. Parents use longer sentences, are more responsive to children's utterances, and introduce more abstract concepts during book sharing [74].

It has been shown that parent-child interaction differs across socioeconomic background, with 'professional' families more likely to be encouraging of children's attempts at communication[70]. Parents can support early reading in various ways, including motivating the child, pointing at pictures, labelling pictures, commenting on the illustrations and providing feedback on children's communicative attempts. Compared to simply reading the text in a book, this social interaction may be particularly beneficial [75]. The benefits of early book sharing might initially be due to the increase in the exposure to spoken language from the parent and new vocabulary that is introduced in these social situations [76]. As children get older and develop their knowledge of print, they tend to focus more on the actual text itself. This is especially true of words that are recognised, and for skilled readers relative to unskilled readers at the same age. It has been suggested that there may be a snowball effect; early book sharing with an adult leads to better letter-reading and comprehension, and children with better comprehension are then more likely to attend to text independently of social support [77].

In extreme situations in which infants are deprived of social contact and interaction, (such as infants that were placed in poor quality orphanages or children's homes early in development) they show deficits in IQ, verbal skills and reading that last into the school years [78,79]. In terms of the brain, there are differences in grey and white matter in children who were raised in institutions such as orphanages[80, 81]. However, factors such as the level of care, staff-to-child ratios and age that the child is placed in the orphanage/children's home make a difference, with "good" orphanages or children's homes being associated with better outcomes [82]. For example, two-to-five year old children in orphanages or children's homes who talked frequently with a single adult had similar vocabulary sizes to children raised in their homes[83]. These results again illustrate the importance of the *quality* of infant-caregiver interactions in the early years[41,84].

Differing environments in development: bilingualism

Infants who are regularly exposed to two native languages tend to pass their language milestones at around the same time as do children who are learning just one (although some studies suggest that they are slightly slower). However, there are clear differences in the language experience they receive. Children learning two languages typically receive less input of each language compared to a monolingual child. In addition, they need to switch between two languages and minimise interference between them. Some authors have suggested that this switching could even enhance their cognitive control and perceptual skills [85]. The ability to keep two languages separate emerges quite early in development; by four months of age Spanish-Catalan infants can differentiate the language spoken despite the very similar rhythm of Spanish and Catalan [86]. Bilingual infants also use a variety of cues to switch between languages, e.g. they will track the rhythm and visual gestures within a language in a way that monolinguals do not [85].

In the earlier sections, we discussed the perceptual tuning of infant's phonological systems. Children who are bilingual tune into the sounds of both of their native languages. However, the developmental changes seen are not straightforward, and they occasionally lose the distinction between sounds in one of their native languages only to reacquire it again later [87].

When it comes to word learning, bilingual children may not weight cues equally. For example, it has been demonstrated that bilinguals do not use the principle of "mutual exclusivity" (see page 14). This is presumably because they realise that one object can have different labels in each of their languages [88].

Bilinguals also differ in their understanding of print. For example, in a test of monolinguals as well as French-English, Chinese-English and Hebrew-English bilinguals between 4-5 years of age, children made judgements about whether a printed word changed meaning when moving to a new location [89]. Here, a printed word ("umbrella") was placed next to an object (say an umbrella) and the child read the word on the card. Afterwards, and seemingly by accident, the experimenter moved the word closer to a different object. The child was asked to read the same word, which was now closer to the different object. To perform correctly, children had to take into account that a word does not change if moved and that the printed word was still "umbrella". All bilingual groups performed better than monolinguals. These results suggest that bilingual children could have an advantage in understanding the symbolic function of print. Other evidence from 7-9 year olds learning to read in bilingual contexts (in this case 50:50 English and Spanish exposure in schools) indicates that bilinguals perform better than monolinguals on passage comprehension and reading irregular words, suggesting that there could be a facilitative effect of bilingualism [90]. However, as these studies do not investigate progress over development, it remains unclear how long this facilitation lasts.

Differing environments in development: writing systems

The most commonplace symbols in the world are the alphabet and number systems (such as Arabic numerals). While learning these symbol systems typically involves some explicit teaching, symbol learning starts much earlier in development [91]. For example, even the age of three, children are able to recognise common symbols such as logos of popular commercial brands that are ubiquitous in modern society. In fact, the more sophisticated a child's reasoning skills are, the more inferences they could make about these symbols, such as the particular values associated with the brand [92].

The nature of the symbol system in use in a particular culture affects the development of literacy [93]. For example, in some scripts such as standard written Chinese, characters represent words. In others, like Japanese, characters represent syllables. In yet others, like English or Italian, characters represent basic sound-level information. In languages such as English or Italian, spelling-sound correspondences may be regular or irregular. In more consistent spelling systems like Italian, children learn to read faster than in less consistent spelling systems like English [91]. However, it is clear that children all over the world learn to read despite these differences in the spelling systems of their language.

Here, we suggest how developmental research might inform the nature of books that are provided for use with young children. We focus on the images used in books, the colours of the images presented, how manipulating books might affect learning, and also how the variability and repetition related to book use plays a role in language learning.

Pictures as symbols: moving from real objects to illustrations

Illustrations prove a positive challenge for young children as they are usually intended to depict a real world object or scene, but obviously (to us as adults) are not the same as the real world item [94]. Importantly, illustrations also represent or symbolise things in the real world. While very young infants can recognise pictures, they tend to treat them as being essentially the same thing as the objects they depict. For example, even newborns can associate a two-dimensional representation (an illustration) with a simple 3D object [95]. Until nine months of age however, infants treat pictures in a similar manner to objects. For example, they manually explore picture books - rubbing, feeling and striking at the picture's surface. Further, the more realistic the pictures are, the more manual exploration is evoked [96,97]. In contrast, older infants (around one and half - two years of age) tend to show a preliminary understanding of the nature of illustrations: when presented with pictures they point to them and/or attempt to label them [97].

So far, there are two studies that suggest experience with pictures affects children's understanding of pictures as symbols. In villages in Peru and India where picture books are less commonly used, three-to-five year old children did not succeed on tasks with illustrations requiring symbolic understanding (the 'false belief' task, to succeed in which one must understand someone else's knowledge can be different from one's own, was used. For example, in a false belief task that employs change in contents, children are asked what is in a box of 'Smarties' bearing the typical label. Subsequent pictures reveal that the contents inside the box were switched from sweets to pencils. The child is then asked to predict what another new person will think is inside the box. The correct answer is 'Smarties', but the Peruvian and Indian children typically said 'pencils'. However, they did succeed in the same false-belief tasks when real objects were used instead of pictures. In contrast, Canadian children with high book experience succeeded on both versions of the task [98]. In a second study, researchers showed that children in Tanzanian villages were slower in learning object names from pictures relative to North American children [99]. These studies suggest that early exposure to pictures may have an effect on children's later comprehension of illustrations and books.

In addition, knowledge derived from illustrations must be generalised to the real world objects that they represent. Research indicates that young children have difficulty transferring information between 2 dimensional and 3 dimensional sources. Children's learning from pictures changes around the same time as they start to understand the nature of pictures. In general, the more realistic the pictorial illustrations, the more children tend to imitate actions depicted in the illustration. While 18-month-olds only imitated actions when they were given colour photographs, 24-month-olds imitated actions when they were given coloured pictures and colour photographs. This suggests that the older children are able to learn from more abstract images[100].

Seeing the visual world in colour

As adults, we perceive an accurate representation of a world composed of differently coloured objects of various sizes, orientations and locations in three-dimensional space. This common sense impression is extraordinary, given that the two-dimensional patterns of light that fall on the retina completely lack these attributes. In many respects, our brains construct our visual world. In the case of colour, the mapping between the wavelength of light that our eyes detect and the colour we consciously perceive is largely constructed within the brain. This can be illustrated by striking illusions in which adults perceive the same colour as being quite different when the surrounding visual scene is changed (such as changing the angle or direction of the primary light source). Our visual system resolves this ambiguity by using its experience of what was seen in the past [101]. The colours we perceive are therefore shaped by our experience over development.

Research indicates that infants develop three types of colour receptors in their retinas (trichromatic) by three months. A recent study suggests that four-month old infants had preferences that were quite different from adult preferences. For example, infants preferred to look at dark yellow hues rather than blues/ greens [102]. However, both adult and infant's preferences interacted with lighting and saturation. It remains unclear why infants preferred these colours. Understanding how children's perception of colour develops and changes according to their visual experience is an important question.

Manipulative elements in books

While it is currently unknown how interacting with a book by turning pages, opening hidden flaps etc. might influence later motor learning, the results from the "sticky mittens" studies[49] mentioned earlier (page 17) indicate that active motor experience tends to facilitate later learning about objects and object properties. However, a recent study contrasting books with manipulative elements to those with realistic images showed that 20-month-olds were distracted by the presence of "pop-ups" when learning facts [103]. More research may be necessary to understand at what age manipulative elements may be beneficial as well as the specific skills for which they might be advantageous.

The importance of attention and variability to learning in the early years

As early as eight months of age, babies can start to extract and remember words from stories that are read to them repeatedly [104]. But when it comes to learning, is it more efficient for adults to repeat items or to introduce novel items? Recent work [105] has shown that reading the same three stories repeatedly (as compared to nine different stories where the words occurred the same number of times) enhances 3-year-old children's long-term memory of words. The authors suggest that hearing the same stories guides attention to the specific words to be learned. On the first reading of a book, children's attention might be drawn to the characters and the plot. In later readings, children's attention might be drawn to the less salient but novel words and therefore add them to their vocabulary. This suggests that children might benefit from predictability and repetition, as this draws their attention away from the overall context and narrative to the individual words they would not otherwise learn. It is important to point out that drawing an infant's attention to a target, and away from the background can also be accomplished in other ways including using social gestures like pointing, removing other objects from view, covering distractors and so on.

However, for some tasks, variability during learning is important. It has been shown that when children do not realise that the targets themselves are variable, drawing attention to such variability is particularly beneficial. For instance, children must extract spelling-to-sound correspondences when learning to read in English. As English is not completely transparent, these spelling-sounds rules are not simple to extract e.g., the ‘e’ in ‘bed’ sounds quite different from the ‘e’ in ‘bead’. It has also been demonstrated that 7-year-old children benefit from learning to read different spelling-sound mappings [106]. Researchers suggest that children should be introduced to different families of spelling-sound mapping early on. Rather than starting with “mat”, “rat”, “bat and so on, word families such as “fan”, “pat”, “pal”, “lap” were recommended. Such variability is also important when extracting grammatical rules (like ‘verb+-ed’ as in “Mary walked there”, “Mary climbed there”). Using words from an artificial language that children did not know, researchers have demonstrated that young children learn these abstract rules (like +ed) only when many different ‘verbs’ are used [107].

While the studies discussed above may appear to conflict in terms of the importance of variability and repetition, what appears to be important for learning is increasing the variability to emphasise the relevant information (this differs by situation; in the examples highlighted above it could be new vocabulary, grammatical structures or spelling-sound correspondences) and decreasing the variation of the background or contextual information. In the early stages of acquiring a skill, repetition may be important, while variability might be beneficial in the later stages of learning.

Summary and conclusions: how can the presence of books in the environment affect development in the early years?

The effects of early experience on brain development are profound. As laid out in this review, the brain is ‘tuned’ by the input from the environment around the child. Neural systems are very sensitive to different forms of this input; for example, newborns can very quickly learn to distinguish sounds in different languages. Here, we have discussed multiple sensitive periods across visual, auditory and social domains. Even within each of these domains, different kinds of input may be necessary at different time points for successful learning. As discussed above, books serve as inputs to influence an infant’s visual, social and linguistic development.

Early book sharing is important for later language and literacy. Rather than this being solely due to early exposure to print [77], book sharing may act as a facilitator of social interaction between adults and children[72]. Because of the prolonged period of postnatal development (Box 1) in humans, social interaction and infant-caregiver bonding is highly important to our species. As discussed, children’s attention to books in concert with parental language can enhance children’s vocabulary. Parental interaction during reading seems to be beneficial - that is, responding to the child’s communicative attempts, providing feedback, labelling objects that the child is interested in and so on [75]. Unlike more passive tasks (for example, watching a TV show), books allow for dynamic engagement between the caregiver and infants. Such switching of attention, between an object and a speaker, has been suggested to facilitate development.

Books also allow for infants to actively engage in and explore the world around them - even before they are able to walk. Early book sharing provides an avenue for infants to elicit information from their caregivers - they may point, gesture or produce speech to get this information. In addition, through manual interaction with books, toddlers learn that pictures are not really objects, but serve as representations of objects. Such symbolic understanding lies at the heart of language and reading. In fact, children growing up in environments where books are less commonplace seem to treat pictures differently from those who are exposed to books regularly.

Importantly, books are a stable source of information throughout childhood. This does not mean that books always contain accurate content (for example, books on fantasy do not accurately represent the world), but that the child can access the same pictures and text in a constant fashion. When parents read to children, children might use this information to learn words, understand what the words refer to and build their sound systems. Books, songs and nursery rhymes introduce children to the patterns characteristic of language through the repetition of certain phrases and rhyming. As children start to read, the familiarity they have built with the words and stories is particularly important to learn the correspondence between letters and sound. Books also serve to introduce new vocabulary and more complex language into children's lives, input that might be particularly important in the early school years.

Books may also be able to serve as a source of input for people growing up in challenging circumstances. For example, some children with visual impairments are reported to have social difficulties. As books can serve to build social and symbolic understanding, books that these children can touch and feel might prove beneficial for their understanding of objects and exploration of the world around them. For these reasons, books are a valuable part of the developing child's environment, and particularly when considering the enhancement of the quality and quantity of parent-child interaction.

Recommendations

1. What is the best age to start to share rhymes, stories and books with children?

In sections I and II, we discussed evidence indicating that children can remember the tune and sounds of language quite early, and even prenatally. Newborns are able to extract information from rhymes and songs.

We suggest that starting to share books at 3 to 4 months may be particularly appropriate. At this age, visual acuity and basic attention skills are sufficiently developed, and infants have a rudimentary ability to begin to explore the world with their hands. In addition, they have an active interest in exploring objects. Evidence suggests that language benefits (measured by later receptive and expressive language ability) may only accrue from shared reading after 8-months of age [108]. Therefore, *the period between 4-8 months appears optimal to begin book sharing with text*.

Story comprehension and understanding of narratives may only emerge by the preschool years. However, as we have highlighted, children may extract other information from stories and may enjoy the changes in the tone of parent's voice as well as the repetition of certain words and phrases. There is no evidence against reading stories before 12 months, but parents should be aware that babies are unlikely to be following the full structure of the story at this stage. Rather, babies may be using this shared activity to build social routines, and to begin their journey towards understanding language and vocabulary.

2. What is the best way for parents to share rhymes, stories and books with children?

As we have highlighted here, young children benefit more from book sharing than book reading. Parents should be responsive to children's attempts to communicate. This means they should ask open-ended questions, shadow their child's interest (or lack of it), and encourage their child to explore different aspects of the book. Book reading helps children learn language when they engage in responsive interactions about word meanings. This is best learnt in a positive and socially engaging context.

We have also discussed the value of both repetition and variability. It seems that repetition is particularly important for younger children, who benefit from hearing the same word often and in different contexts. Parents should also be aware that children focus on different components of a book at different ages. Infants start with extracting pictures from the visual scenes, then learning new words, but progress to learning more about the stories, characters and routines in books by the preschool years. They may be able to extract different information over multiple readings of the same book. However, the interactive component may help to introduce variability in the language that parents use, ensuring that it is targeted at the child's level.

While it has been shown that learning is more efficient in social situations using books and toys (as compared to passively watching TV), research on how digital media (for example, books delivered on an iPad or kindle) will contrast with more traditional paper books[109] has only just begun and was not the focus of this review. Unlike TVs, such electronic devices do allow for social interaction and manual exploration by the child. Yet, the content displayed on the device is more transitory in nature, suggesting that there may be differences in the skills children learn from these devices [110]. Please see the cited papers for further information on this area of research. We recommend further research on this topic, considering its importance in modern day living.

3. How do environmental factors affect language and literacy development?

Bilingual environments can affect children's language development in that they use different strategies for learning. This is not a disadvantage when learning language or becoming literate, and in some specific cases may even be an advantage. Considering the real-world benefits of speaking multiple languages, we endorse the continuing use of all languages in multi-lingual homes.

Socioeconomic differences may affect language and literacy. In this regard, shared book reading, especially when child-focused may be particularly beneficial in changing existing language trajectories and levelling the field for school entry. In book sharing parents should be child-focused and provide encouragement to children to make their wishes and desires about the book clear.

Other environments discussed here include being born blind or deaf. For deaf children, it is clear that visual language input is key. Especially for deaf children born to hearing families, books that include "sign and sing along" may provide one way for parents to engage and create social and language environments for their children. Rhymes, songs and social routines are likely to be valuable for children with visual impairments, again, because they help create shared social experiences and a context for further learning. More research is required into how the early tactile experience of books and toys could benefit these children. Targeted programmes, such as Bookstart Corner, Bookshine, and Booktouch aim to provide additional support for families who need it and, while the current literature on how books play a role in developing symbolic representations is encouraging, further research on the effects of these programmes is strongly recommended.

Other factors associated with poor language and literacy outcomes later in life are self-control and attention. An open question in this regard is whether de-cluttering the visual scene (to make children focus on one object at a time) is beneficial for children who are easily distracted. Parents may be able to do this by covering other objects, pointing to the object in question and using other means to direct children's interest to the object of interest. Removing distractors (such as switching off the competing TV/radio) may be useful in helping children focus on the book.

Executive Summary

This report reviews current evidence on human brain and behavioural development over the early years, specifically in relation to the sensory and cognitive "toolkit" of abilities relevant to book use and enjoyment. Based on current research findings from studies of infants we recommend that book experiences commence from 3 or 4 months of age, with evidence that such experiences benefit later language and communicative skills from 8 months. The sharing experience of books between parents and their infants provides a rich context for developing a variety of social skills known to be critical for facilitating later learning. Further, multiple readings of the same book within a social interactive context provides both the degree of repetition and variability necessary for optimal learning. Such experiences in the early years have the potential to equalise imbalances in pre-schoolers readiness for school education. Little is currently known about whether electronic books have the same or different benefits. Research is also urgently required on the effects of early book experience

on infants with sensory limitations or developmental disorders. Children's ability to adapt to different early environments (such as bilingualism, deafness, poor sight) may be enhanced by the use of appropriately modified books as these afford the opportunity to strengthen communication skills around shared materials.

Acknowledgements

We would like to thank Daniel Carey, Kate Hughes, Dr. Tessa Dekker, Dr. Fred Dick, Dr. Bob McMurray, Dr. Victoria Knowland, Prof. Annette Karmiloff-Smith and Prof. Michael Thomas for their comments and reading suggestions.

Box 1: What makes the human brain unique? [111,112].

The brains of all mammals follow a basic vertebrate brain plan that is found even in species such as salamanders, frogs, and birds. Despite the evolutionary continuity in this basic plan, one of the major differences between these species and higher primates (such as chimpanzees and humans) is in the dramatic expansion of the cortex, together with its associated structures (such as the basal ganglia).

As a first approximation, across different species brain size correlates with both body size and the length of developmental time it takes to reach its adult size. As large mammals, primates generally have a much more prolonged timetable for brain development than other mammals. However, even between Homo sapiens and other primates there is a wide difference in timing. In particular, our species' period of postnatal cortical development is extended by roughly a factor of four compared to our closest cousin species.

Thus, while humans have the survival disadvantage of being born relatively immature and largely immobile, this prolonged period of postnatal development allows more time for social and physical environments to contribute to the tuning and shaping of brain circuitry. Viewed from this perspective, the high importance of parent-infant bonding and interaction as part of the constructed niche of our species becomes evident.

Box 2: A neuromyth – the Left/Right Brain [113,114]

A popular idea is that the “left brain” is responsible for completely different functions than the “right brain”. Further, it is suggested that each hemisphere can be trained independently, as if they were two different miniature brains. This myth is based on the reality that in adults, greater left hemisphere activation is often observed for certain activities (such as processing language), and greater right hemisphere activation is typically seen for other tasks (such as viewing faces). Some studies in infants suggest that these patterns may be present at birth, for instance, left hemisphere dominance for language. However, other evidence suggests that other examples of hemispheric specialization clearly emerge during childhood, and possibly also during the acquisition of reading. Claims about hemispheric specialization need to always be critically assessed as (1) they are often based on average results across a population, and there are usually many examples of individuals that show different patterns of specialization, e.g. around 90% of right-handed adults have language localized to the left hemisphere, but this is true of only 67% of left-handed individuals; (2) nearly always, both hemispheres show some involvement in all tasks, and (3) details of the baseline measures used can change the apparent patterns of specialization observed.

Box 3: Selective loss/ training in early visual development [115]

Newborns can discriminate between a number of different faces, from different races as well as different species. With experience, children's ability to recognise faces becomes restricted to those with which they are most familiar (human faces from their own ethnic group) and they lose the ability to distinguish faces of other species. Such "pruning" is similar to the 'rise and fall' pattern discussed in Section I. For example, while 6-month olds, 9-month olds and adults are equally good at discriminating between two human faces, only 6-month olds are able to discriminate between monkey faces. Pascalis and colleagues (2005) conducted a training study to explore whether this loss was due to experience. A group of 6-month-old human infants were regularly shown six Barbary monkey faces using picture books for three months. Each monkey had a name, and parents showed children the books for about 1-2 minutes every day for three months. This group of 6-month-olds was tested at the end of training, that is, when they were 9-month-olds. In contrast to untrained 9-month-olds who had not been exposed to many monkey faces, the trained infants did not lose their ability to discriminate monkey faces. These findings illustrate how experience with books can shape the development of the visual system.

Box 4: The role of music in childhood [27,116,117]

Most children acquire their basic musical skills through everyday exposure to music. Regardless of formal training, this everyday listening exposure allows them to follow the rhythm and experience the emotional content of music as well as remember and recall familiar tunes.

Adults and infants both show greater difficulty differentiating between sounds that lack harmony relative to harmonic sounds. With listening experience, the auditory system is trained to expect the musical structure of the child's cultural environment. For example, Western adults have expectations and preferences for the harmony of a melody. Experiments with 8-month-old infants indicate that they have no specific preferences for the harmony associated with their culture. These cultural preferences only emerge by the age of 6-7 years. However, there is some work suggesting that if newborns are familiar with the music being played, a harmonic alteration can lead to different brain responses. It is therefore unclear how to relate children's behavioural responses to their brain responses with respect to harmony.

In contrast to harmonic skills, rhythmic discrimination is observed fairly early on (in fact, as early as two months of age). There is some indication that this may develop as a consequence of biological or regular movement - for example, bouncing a child to a particular rhythm affected how they interpreted an auditory rhythm. Some scientists believe that the rhythmic nature of speech and particularly songs and nursery rhymes might help infants find the words in their language and understand how to segment words into finer sound units.

While the content of speech and music is clearly different, the brain networks that subserve listening and detection of violations for both speech and music overlap substantially (even in newborns). Some studies suggest that infants may have a less clear demarcation between speech and music. Indeed, speech directed at infants by adults has a sing-song nature (often called "motherese").

There is emerging evidence that formal musical training may enhance sensitivity to rhythms in language, the detection of violations in pitch during speech and the ability to pick up syntactic structure. During early childhood, there may also be small effects of formal musical training on general skills such as attention and executive functioning, which may be of overall benefit during learning. However, how long these benefits might last has not been established.

Appendix 1: Building a brain: Prenatal development

The life story of a neuron: the formation of the central nervous system

The sequence of events involved in the prenatal development of the human brain closely resembles that of many other vertebrates. The fertilised egg initially divides to form a cluster of cells. This cluster then differentiates into a three-layered structure; each layer of which gives rise to different organ systems. The outermost layer gives rise to the nervous system and brain. A portion of the outer layer folds in on itself to form a hollow cylinder, which then differentiates further to form the major subdivisions of the central nervous system with the forebrain and midbrain arising at one end of this cylinder and the spinal cord at the other. A series of bulges and convolutions form at the brain end of the neural tube. Around five weeks after conception, these bulges can be identified as the foundations for different parts of the brain such as the cortex, the midbrain and the cerebellum.

The life story of a neuron: birth

Differentiation within the different bulges gives rise to the complex layering patterns and cell types found in the adult brain. Within these bulges, cells are born, travel, and change form into particular types of neurons and supporting cells. The majority of brain cells are born in two zones (ventricular/ subventricular) that are situated close to the hollow part of the neural tube. These two zones yield separate cell lines (glial cells and neurons). These are produced by division of cells in these cells to produce clones (a group of cells which are produced by division of a single precursor cell). In some cases, particular precursor cells give rise to specific types of cells or neurons. Cells in the ventricular zone gives rise to subcortical structures such as the midbrain and thalamus, whereas the cells in the sub-ventricular zone form to the cortex.

The life story of a neuron: migration

After young neurons are born, they travel or migrate from the zones they are born in to the region where they are located in the mature brain. The first and more common type of migration is passive. This occurs when cells that have been generated are then simply pushed further away from the two zones mentioned earlier by more recently born cells. This form of migration gives rise to an “outside-in” pattern with the oldest cells get pushed toward the surface of the brain, while the most recently generated cells remain closer to their place of birth. Passive migration gives rise to subcortical brain structures such as the thalamus, the hippocampus, and parts of the brain stem.

The second form of migration is more active and involves the young cell moving past previously generated cells to create an "inside-out" pattern. This pattern is found in the cerebral cortex. With the subventricular zone, each mother (precursor) cell gives rise to approximately one hundred neurons. These neurons all migrate along the same route, with the youngest travelling past their older cousins. The route they take is determined by following a radial fibre - a long process that stretches from top to bottom of the cortex and originates from a supporting cell. These fibres act like a guidance rope to help ensure that cells produced by one precursor unit all contribute to one radial column within the cortex.

Migration of neurons to the cortex peaks around 12-20 weeks after conception and is complete by 26-29 weeks. By the time of birth in humans, the vast majority of neurons have been born, migrated to their final locations, and have differentiated into recognisable types. The main lobes of the cortex are also developed. Nevertheless, a very considerable portion of human brain development continues into postnatal years.

Appendix 2: Brain oscillations

Even simple nervous systems show spontaneous activity that is only sometimes driven by sensory or motor events. Oscillatory activity (rhythmic, repetitive activity) is a fundamental property of the brain. In human brains, oscillatory activity can occur at multiple different frequencies simultaneously. Oscillations at different frequencies are not mere reflections of patterns of neuron firing; they are also thought to play a role in binding activity states across near and far regions of the brain. Indeed, some researchers have argued that specific oscillation frequencies characterise distinct functional networks, and keep their information processing distinct from other regions.

In development, some of these spontaneous rhythms may have particular importance in building the appropriate connections between regions. This is even before inputs from the external world have any effect. For instance, patterns of spontaneous firing of cells within the eyes (before they have opened and exposed themselves to light) transmit signals that help induce the structure of a critical visual relay region. The role of external sensory stimulation may be to tweak and fine-tune the oscillation patterns in our sensory systems.

Sources and further reading

1. Attwell, D. & Laughlin, S. B. An energy budget for signaling in the grey matter of the brain. *J Cereb Blood Flow Metab* **21,** 1133–1145 (2001).
2. Volpe, J. J. *Neurology of the Newborn*. (Saunders, 2008).
3. Anderson, A. L. & Thomason, M. E. Functional plasticity before the cradle: A review of neural functional imaging in the human fetus. *Neuroscience and Biobehavioral Reviews* **37,** 2220–2232 (2013).
4. Hepper, P. G. An Examination of Fetal Learning Before and After Birth. *The Irish Journal of Psychology* **12,** 95–107 (1991).
5. DeCasper, A. J. & Spence, M. J. Prenatal maternal speech influences newborns' perception of speech sounds. *Infant Behavior and Development* **9,** 133–150 (1986).
6. Moon, C., Lagercrantz, H. & Kuhl, P. K. Language experienced in utero affects vowel perception after birth: a two-country study. *Acta Paediatr.* **102,** 156–160 (2013).
7. Doria, V. *et al.* Emergence of resting state networks in the preterm human brain. *Proceedings of the National Academy of Sciences* **107,** 20015–20020 (2010).
8. Fransson, P. *et al.* Resting-state networks in the infant brain. *Proc Natl Acad Sci USA* **104,** 15531–15536 (2007).
9. Supekar, K. S., Musen, M. & Menon, V. Development of large-scale functional brain networks in children. *PLoS Biol* **7,** e1000157 (2009).
10. Fair, D. A. *et al.* The maturing architecture of the brain's default network. *Proceedings of the National Academy of Sciences* **105,** 4028–4032 (2008).
11. Thompson, R. A. & Nelson, C. A. Developmental science and the media: Early brain development. *American Psychologist* **56,** 5–15 (2001).
12. Casey, B. J., Tottenham, N., Liston, C. & Durston, S. Imaging the developing brain: what have we learned about cognitive development? *Trends in Cognitive Sciences* **9,** 104–110 (2005).
13. Huttenlocher, P. R. Morphometric study of human cerebral cortex development. *Neuropsychologia* **28,** 517–527 (1990).
14. Huttenlocher, P. R. & Dabholkar, A. S. Regional differences in synaptogenesis in human cerebral cortex. *J Comp Neurol* **387,** 167–178 (1997).
15. Benes, F. M. in *Human behavior and the developing brain* (Dawson, G. & Fischer, K. W.) 176–206 (1994). doi:10.1002/cd.23219832106/abstract
16. Ben-Ari, Y., Khalilov, I., Kahle, K. T. & Cherubini, E. The GABA Excitatory/Inhibitory Shift in Brain Maturation and Neurological Disorders. *The Neuroscientist* **18,** 467–486 (2012).
17. Thomas, M. & Knowland, V. Sensitive periods in brain development–implications for education policy. *European Psychiatric Review* (2009).
18. Brenowitz, E. A. & Beecher, M. D. Song learning in birds: diversity and plasticity, opportunities and challenges. *Trends Neurosci* **28,** 127–132 (2005).
19. Zevin, J. D. A sensitive period for shibboleths: the long tail and changing goals of speech perception over the course of development. *Dev Psychobiol* **54,** 632–642 (2012).
20. Johnson, M. H. Sensitive periods in functional brain development: problems and prospects. *Dev Psychobiol* **46,** 287–292 (2005).
21. Johnson, M. H. *Developmental Cognitive Neuroscience*. (John Wiley & Sons, 2011).
22. Bavelier, D., Levi, D. M., Li, S. J., Dan, Y. & Hensch, T. K. Removing brakes on

adult brain plasticity: from molecular to behavioral interventions. *Journal of Neuroscience* **30,** 14964–14971 (2010).
23. Lim, S.-J. & Holt, L. L. Learning Foreign Sounds in an Alien World: Videogame Training Improves Non-Native Speech Categorization. *Cogn Sci* **35,** 1390–1405 (2011).
24. Cohen Kadosh, K. & Johnson, M. H. Developing a cortex specialized for face perception. *Trends in Cognitive Sciences* **11,** 367–369 (2007).
25. Scherf, K. S., Behrmann, M., Humphreys, K. & Luna, B. Visual category-selectivity for faces, places and objects emerges along different developmental trajectories. *Developmental Science* **10,** F15–30 (2007).
26. Schlaggar, B. L. & McCandliss, B. D. Development of neural systems for reading. *Annu Rev Neurosci* **30,** 475–503 (2007).
27. Ullal-Gupta, S., Vanden Bosch der Nederlanden, C. M., Tichko, P., Lahav, A. & Hannon, E. E. Linking prenatal experience to the emerging musical mind. *Front. Syst. Neurosci.* **7,** (2013).
28. Vouloumanos, A., Werker, J. F., Hauser, M. D. & Martin, A. The tuning of human neonates' preference for speech. *Child Dev* **81,** 517–527 (2010).
29. Saffran, J. R., Werker, J. F. & Werner, L. A. The infant's auditory world: Hearing, speech, and the beginnings of language. *Handbook of child psychology* (2006).
30. Zevin, J. D. & Seidenberg, M. S. Age of acquisition effects in word reading and other tasks. *Journal of Memory and Language* **47,** 1–29 (2002).
31. Rvachew, S. & Savage, R. Preschool foundations of early reading acquisition. *Paediatr Child Health* **11,** 589–593 (2006).
32. Beattie, R. L. & Manis, F. R. The relationship between prosodic perception, phonological awareness and vocabulary in emergent literacy. *Journal of Research in Reading* **37,** 119–137 (2011).
33. Maclean, M., Bryant, P. & Bradley, L. Rhymes, Nursery Rhymes, and Reading in Early Childhood. *Merill-Palmer Quarterly* **33,** 255–281 (1987).
34. Cartwright, K. B. Insights From Cognitive Neuroscience: The Importance of Executive Function for Early Reading Development and Education. *Early Education & Development* **23,** 24–36 (2012).
35. Nation, K. & Hulme, C. Learning to read changes children’s phonological skills: evidence from a latent variable longitudinal study of reading and nonword repetition. *Developmental Science* **14,** 649–659 (2010).
36. Saffran, J. R., Aslin, R. & Newport, E. Statistical learning by 8-month-old infants. *Science* **274,** 1926 (1996).
37. Werker, J. F. & Stager, C. L. Developmental changes in infant speech perception and early word learning: Is there a link. *Papers in laboratory phonology* **5,** 181–193 (2000).
38. McMurray, B., Horst, J. S. & Samuelson, L. K. Word learning emerges from the interaction of online referent selection and slow associative learning. *Psychol Rev* **119,** 831–877 (2012).
39. Munro, N., Baker, E., McGregor, K. & Docking, K. Why word learning is not fast. *Frontiers in Psychology* (2012). doi:10.3389/fpsyg.2012.00041
40. Fenson, L. *et al.* Variability in early communicative development. *Monographs of the Society for Research in Child Development* **59,** 1–173– discussion 174–85 (1994).
41. Dick, F., Leech, R. & Richardson, F. M. in *Child Neuropsychology Concepts, Theory, and Practice* (Reed, J. & Warner-Rogers, J.) (Child Neuropsychology, 2007).

42. Slater, A. in *The Wiley-Blackwell Handbook of Infant Development* (Bremner, J. G. & Fogel, A.) 5–34 (Wiley-Blackwell, 2010).
43. Jandó, G. *et al.* Early-onset binocularity in preterm infants reveals experience-dependent visual development in humans. *Proceedings of the National Academy of Sciences* **109,** 11049–11052 (2012).
44. Banks, M. S. & Shannon, E. in *Visual Perception and Cognition in Infancy* (Granrud, C.) 1–46 (1993).
45. Johnson, S. P. in *Neural Circuit Development and Function in the Brain* 249–269 (Elsevier, 2013). doi:10.1016/B978-0-12-397267-5.00033-9
46. Kellman, P. J. & Spelke, E. S. Perception of partly occluded objects in infancy. *Cogn Psychol* **15,** 483–524 (1983).
47. Johnson, S. P. & Aslin, R. N. Perception of object unity in young infants: The roles of motion, depth, and orientation. *Cognitive Development* (1996).
48. Mareschal, D. & Johnson, M. H. The “what” and “where” of object representations in infancy. *COGNITION* (2003). doi:10.1016/S0010-0277(03)00039-8
49. Needham, A., Barrett, T. & Peterman, K. A pick-me-up for infants’ exploratory skills: Early simulated experiences reaching for objects using ‘sticky mittens’ enhances young infants’ object exploration skills. *Infant Behavior and Development* **25,** 279–295 (2002).
50. Barrett, T. M. & Needham, A. Developmental differences in infants‘ use of an object’s shape to grasp it securely. *Dev Psychobiol* **50,** 97–106 (2008).
51. Libertus, K. *et al.* Size matters: How age and reaching experiences shape infants’ preferences for different sized objects. *Infant Behavior and Development* **36,** 189–198 (2013).
52. Tomasello, M., Carpenter, M., Call, J., Behne, T. & Moll, H. Understanding and sharing intentions: the origins of cultural cognition. *Behav Brain Sci* **28,** 675–91–discussion 691–735 (2005).
53. Kuhl, P. K., Tsao, F.-M. & Liu, H.-M. Foreign-language experience in infancy: effects of short-term exposure and social interaction on phonetic learning. *Proceedings of the National Academy of Sciences* **100,** 9096–9101 (2003).
54. Goldstein, M. H., King, A. P. & West, M. J. Social interaction shapes babbling: testing parallels between birdsong and speech. *Proc Natl Acad Sci USA* **100,** 8030–8035 (2003).
55. Goldstein, M. H. & Schwade, J. A. Social feedback to infants' babbling facilitates rapid phonological learning. *Psychological Science* **19,** 515–523 (2008).
56. Hoff, E. How social contexts support and shape language development. *Developmental Review* (2006). doi:10.1016/j.dr.2005.11.002
57. Mundy, P. & Jarrold, W. Infant joint attention, neural networks and social cognition. *Neural Networks* **23,** 985–997 (2010).
58. Carpenter, M., Nagell, K., Tomasello, M., Butterworth, G. & Moore, C. Social Cognition, Joint Attention, and Communicative Competence from 9 to 15 Months of Age. *Monographs of the Society for Research in Child Development* **63,** i (1998).
59. Butterworth, G. in *The Wiley-Blackwell Handbook of Infant Development* (Bremner, J. G. & Fogel, A.) 213–240 (Wiley-Blackwell, 2010).
60. Greenough, W. T., Black, J. E. & Wallace, C. S. Experience and brain development. *Child Dev* **58,** 539–559 (1987).
61. Lewis, T. L. & Maurer, D. Multiple sensitive periods in human visual development: Evidence from visually deprived children. *Dev Psychobiol* **46,** 163–183 (2005).
62. Maurer, D., Mondloch, C. J. & Lewis, T. L. Sleeper effects. *Developmental Science* **10,** 40–47 (2007).

63. Le Grand, R., Mondloch, C. J., Maurer, D. & Brent, H. P. Impairment in holistic face processing following early visual deprivation. *Psychological Science* **15,** 762–768 (2004).
64. Senju, A. *et al.* The importance of the eyes: communication skills in infants of blind parents. *Proceedings of the Royal Society B: Biological Sciences* **280,** 20130436 (2013).
65. Bavelier, D. & Neville, H. J. Cross-modal plasticity: where and how? *Nat Rev Neurosci* **3,** 443–452 (2002).
66. Finney, E. M., Fine, I. & Dobkins, K. R. Visual stimuli activate auditory cortex in the deaf. *Nat Neurosci* **4,** 1171–1173 (2001).
67. Homae, F., Watanabe, H., Nakano, T. & Taga, G. Large-scale brain networks underlying language acquisition in early infancy. *Front. Psychology* **2,** 93 (2011).
68. Lyness, C. R., Woll, B., Campbell, R. & Cardin, V. How does visual language affect crossmodal plasticity and cochlear implant success? *Neuroscience and Biobehavioral Reviews* **37,** 2621–2630 (2013).
69. Harlaar, N., Hayiou-Thomas, M. E., Dale, P. S. & Plomin, R. Why do preschool language abilities correlate with later reading? A twin study. *J Speech Lang Hear Res* **51,** 688–705 (2008).
70. Hart, B. & Risley, T. R. *Meaningful differences in the everyday experience of young American children.* (Paul H Brookes Publishing, 1995).
71. Thomas, M. S. C. & Knowland, V. C. P. Modeling mechanisms of persisting and resolving delay in language development. *J. Speech Lang. Hear. Res.* **57,** 467–483 (2014).
72. Protzko, J., Aronson, J. & Blair, C. How to Make a Young Child Smarter Evidence From the Database of Raising Intelligence. *Perspectives on Psychological Science* (2013).
73. Evans, M. A. & Saint-Aubin, J. What children are looking at during shared storybook reading evidence from eye movement monitoring. *Psychological Science* **16,** 913–920 (2005).
74. Fletcher, K. L. & Reese, E. Picture book reading with young children: A conceptual framework. *Developmental Review* **25,** 64–103 (2005).
75. Bus, A. G., Belsky, J., van Ijzendoom, M. H. & Crnic, K. Attachment and bookreading patterns: A study of mothers, fathers, and their toddlers. *Early Childhood Research …* **12,** 81–98 (1997).
76. Korat, O. & Haglili, S. Maternal evaluations of children‘s emergent literacy level, maternal mediation in book reading, and children's emergent literacy level: A comparison between SES …. *Journal of Literacy Research* **39,** 249–276 (2007).
77. Mol, S. E. & Bus, A. G. To read or not to read: A meta-analysis of print exposure from infancy to early adulthood. *Psychological Bulletin* **137,** 267–296 (2011).
78. Frank, D. A., Klass, P. E., Earls, F. & Eisenberg, L. Infants and Young Children in Orphanages: One View From Pediatrics and Child Psychiatry. *Pediatrics* **97,** 569–578 (1996).
79. Windsor, J., Glaze, L. E. & Koga, S. F. Language Acquisition With Limited Input: Romanian Institution and Foster Care. *J Speech Lang Hear Res* **50,** 1365–1381 (2007).
80. Mehta, M. A. *et al.* Amygdala, hippocampal and corpus callosum size following severe early institutional deprivation: The English and Romanian Adoptees Study Pilot. *Journal of Child Psychology and Psychiatry* **50,** 943–951 (2009).
81. Tottenham, N. *et al.* Prolonged institutional rearing is associated with atypically large amygdala volume and difficulties in emotion regulation. *Developmental*

Science **13,** 46–61 (2010).
82. Biemiller, A. Vocabulary: Needed if more children are to read well. *Reading Psychology* (2003). doi:10.1080/02702710390227297
83. Tizard, B., Cooperman, O., Joseph, A. & Tizard, J. Environmental effects on language development: A study of young children in long-stay residential nurseries. *Child Dev* (1972).
84. Tierney, A. L. & Nelson, C. A., III. Brain development and the role of experience in the early years. *Zero to three* (2009).
85. Werker, J. Perceptual foundations of bilingual acquisition in infancy. *Annals of the New York Academy of Sciences* **1251,** 50–61 (2012).
86. Bosch, L. & Sebastián-Gallés, N. Evidence of early language discrimination abilities in infants from bilingual environments. *Infancy* (2001).
87. Sebastián-Gallés, N. & Bosch, L. Developmental shift in the discrimination of vowel contrasts in bilingual infants: is the distributional account all there is to it? *Developmental Science* **12,** 874–887 (2009).
88. Houston-Price, C., Caloghiris, Z. & Raviglione, E. Language Experience Shapes the Development of the Mutual Exclusivity Bias. *Infancy* **15,** 125–150 (2010).
89. Bialystok, E., Shenfield, T. & Codd, J. Languages, scripts, and the environment: Factors in developing concepts of print. *Dev Psychol* **36,** 66–76 (2000).
90. Kovelman, I., Baker, S. A. & Petitto, L.-A. Age of first bilingual language exposure as a new window into bilingual reading development. *Bilingualism* **11,** 203–223 (2008).
91. Goswami, U. *Cognitive Development*. (Psychology Press (UK), 2008).
92. McAlister, A. R. & Cornwell, T. B. Children's brand symbolism understanding: Links to theory of mind and executive functioning. *Psychology & Marketing* **27,** 203–228 (2010).
93. Ziegler, J. C. & Goswami, U. Becoming literate in different languages: similar problems, different solutions. *Developmental Science* **9,** 429–436 (2006).
94. DeLoache, J. S. Becoming symbol-minded. *Trends in Cognitive Sciences* **8,** 66–70 (2004).
95. Preissler, M. A. & Bloom, P. Two-year-olds appreciate the dual nature of pictures. *Psychological Science* **18,** 1–2 (2007).
96. Pierroutsakos, S. L. & DeLoache, J. S. Infants' manual exploration of pictorial objects varying in realism. *Infancy* (2003).
97. Ganea, P. A., Pickard, M. B. & DeLoache, J. S. Transfer between Picture Books and the Real World by Very Young Children. *Journal of Cognition and Development* **9,** 46–66 (2008).
98. Callaghan, T. C., Rochat, P. & Corbit, J. Young Children's Knowledge of the Representational Function of Pictorial Symbols: Development Across the Preschool Years in Three Cultures. *Journal of Cognition and Development* **13,** 320–353 (2012).
99. Walker, C. M., Walker, L. B. & Ganea, P. A. The role of symbol-based experience in early learning and transfer from pictures: Evidence from Tanzania. *Dev Psychol* **49,** 1315–1324 (2013).
100. Simcock, G. & DeLoache, J. S. The Effect of Repetition on Infants' Imitation From Picture Books Varying in Iconicity. *Infancy* **13,** 687–697 (2008).
101. Beau Lotto, R. Visual Development: Experience Puts the Colour in Life. *Current Biology* **14,** R619–R621 (2004).
102. Taylor, C., Schloss, K., Palmer, S. E. & Franklin, A. Color preferences in infants and adults are different. *Psychonomic Bulletin & Review* **20,** 916–922 (2013).

103. Tare, M., Chiong, C., Ganea, P. & DeLoache, J. Less is more: How manipulative features affect children's learning from picture books. *Journal of Applied Developmental Psychology* **31,** 395–400 (2010).
104. Jusczyk, P. W. & Hohne, E. A. Infants' memory for spoken words. *Science* **277,** 1984–1985 (1997).
105. Horst, J. S. Context and repetition in word learning. *Front. Psychology* **4,** 149 (2013).
106. Apfelbaum, K. S., Hazeltine, E. & McMurray, B. Statistical learning in reading: Variability in irrelevant letters helps children learn phonics skills. *Dev Psychol* **49,** 1348–1365 (2013).
107. Gomez, R. L. Variability and detection of invariant structure. *Psychological Science* **13,** 431–436 (2002).
108. Karrass, J. & Braungart-Rieker, J. M. Effects of shared parent–infant book reading on early language acquisition. *Journal of Applied Developmental Psychology* **26,** 133–148 (2005).
109. Kucirkova, N. Children's interactions with iPad books: research chapters still to be written. *Front. Psychology* **4,** 995 (2013).
110. Parish Morris, J., Mahajan, N., Hirsh-Pasek, K., Golinkoff, R. M. & Collins, M. F. Once Upon a Time: Parent–Child Dialogue and Storybook Reading in the Electronic Era. *Mind, Brain, and Education* **7,** 200–211 (2013).
111. Finlay, B. L. & Darlington, R. B. Linked regularities in the development and evolution of mammalian brains. *Science* **268,** 1578–1584 (1995).
112. Finlay, B. L. & Workman, A. D. Human exceptionalism. *Trends in Cognitive Sciences* **17,** 199–201 (2013).
113. Dehaene-Lambertz, G. *et al.* Nature and nurture in language acquisition: anatomical and functional brain-imaging studies in infants. *Trends Neurosci* **29,** 367–373 (2006).
114. Perani, D. *et al.* Neural language networks at birth. *Proceedings of the National Academy of Sciences* **108,** 16056–16061 (2011).
115. Pascalis, O. *et al.* Plasticity of face processing in infancy. *Proc Natl Acad Sci USA* **102,** 5297–5300 (2005).
116. Hannon, E. E. & Trainor, L. J. Music acquisition: effects of enculturation and formal training on development. *Trends in Cognitive Sciences* **11,** 466–472 (2007).
117. Perani, D. *et al.* Functional specializations for music processing in the human newborn brain. *Proceedings of the National Academy of Sciences* **107,** 4758–4763 (2010).
118. Johnson, M.H. (in press). Neurobiological perspectives on developmental psychopathology. *Rutter's Child and Adolescent Psychiatry*, 6th edition.