What happens in the brain as very young children learn

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Neuroscience is increasingly showing that common assumptions about rearing children need to be reviewed and adjusted if we want to nurture individuals who will build societies that are harmonious, hospitable, respectful and productive. This article explains what physically happens in the brain as children learn, before birth and in their earliest years of life, laying foundations on which future structures can be built.

Children's neurological development in early life is a continuous process, as all learning builds on things learned before. For example, a child begins to hold his or her head erect, while supported on a lap, at around the third to fifth month of life. In order to sit up by themselves, children have to be able to support their own head, and also need good upper body posture, a skill that will be acquired only around the sixth to tenth month. Later on, in order to walk, children need to have mastered posture and hip balance through the previous learning stages of being able to stand alone and then take steps; learning that happens between 10 and 18 months of age.

More complex activities, such as auditory and visual discrimination, language and attention, are also highly dependent on previous pillars. This premise is valid for all functional aspects: there are no omissions in these sequences. And these advances do not occur automatically; three interrelated and mutually reinforcing conditions are required for development to occur:

- Neurobiological structure – the nervous system, especially the brain, must be mature and ready for learning.
- Stimulus – children must be encouraged to learn; usually, such stimuli are promoted by parents, relatives and caregivers.
- Affection – a welcoming environment is key for the establishment and continuation of development.

How the brain is formed

The structuring of the nervous system starts in the womb a few weeks after conception, with the formation of the neural tube (Volpe, 2008), from which develop the brain, the brain stem and the spinal cord (Figure 1).

Figure 1 Neural tube

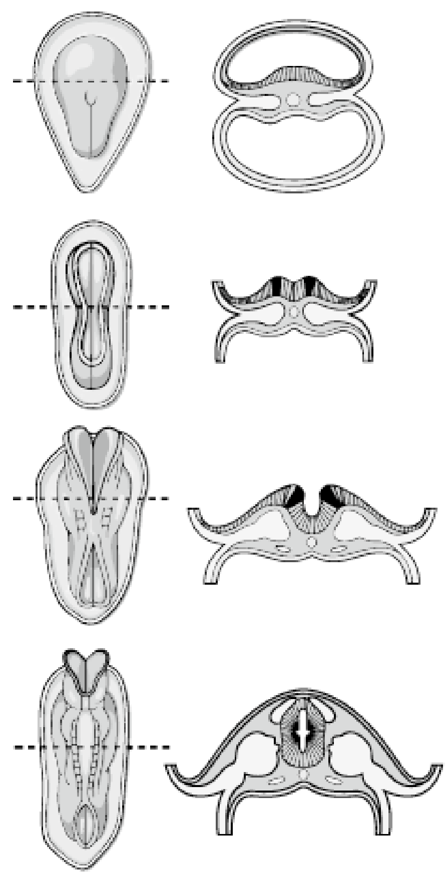


Image: Courtesy LifeART Medical Illustrations

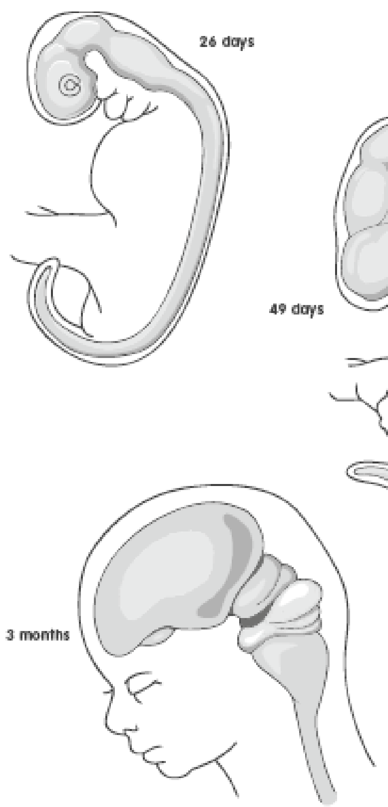
As the weeks go by, visible modifications occur that will lead to differentiation of the various areas of the brain, with the progressive formation of the cerebral hemispheres (Figures 2 and 3).

Simultaneously, the brain's microstructures undergo ever more complex modifications as neural circuits are organised, preparing individuals for the task of learning (Figure 4).

The brain's maturation process happens in four phases:

1. *Neuron multiplication*
   Between the tenth and the fourteenth week of pregnancy, young neurons start an exuberant process of multiplication, forming around 90 billion new neurons.

Figure 2 Brain development during pregnancy



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2 *Migration and organisation of cell architecture*
Once formed, neurons migrate to a final predetermined location in one of the regions of the brain. Each neuron's 'address' is defined on a specific layer in the cerebral cortex, in one of the six existing layers, and must be correctly positioned to make up, on the whole, what is known as 'grey matter' (the outermost layer of the brain).

3 *Synapses (connections between neurons)*
Once they get to the place where they are designed to be, neurons start interacting with one another through dendrites and axons, forming contacts we call synapses. These connections receive, conduct and disseminate information around the brain, forming an ultra-complex communication network. During the first year of life this network is formed at the incredible speed of 700 new connections per second.

Figure 3 Newborn brain

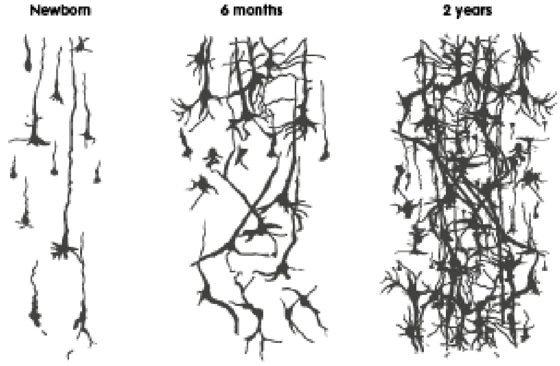
Image: Courtesy LifeART Medical Illustrations

4 *Myelination (neuronal coating)*
The connections that create brain circuits are progressively coated with a myelin sheath which, like the sheath on electric wires, helps to avoid short-circuits and losses during the transmission of information. Myelination starts very early in life and continues for many decades, offering individuals the possibility always to continue learning (Figure 5).

How brain communication occurs

For a neuron to transmit stimuli to another neuron, it requires a neurotransmitter – that is, a substance that facilitates the traffic of information. The most important neurotransmitters are dopamine, acetylcholine and serotonin. They are produced by specific neuron nuclei located in the brainstem, the structure of the nervous system between the brain and the spinal cord. Neurotransmitters support the smooth

Figure 4. Evolution of brain circuit organisation



Source: Conel, 1959

Figure 5 Neuron and axon with myelin sheath

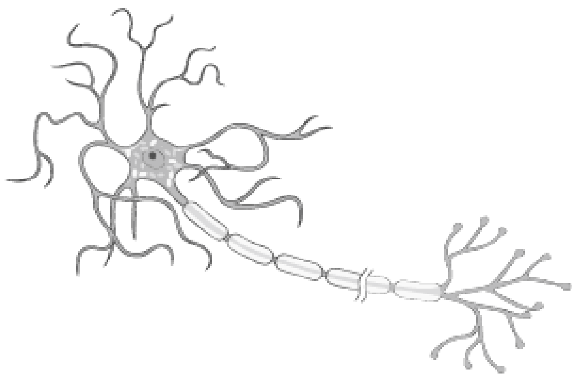


Image: Courtesy LifeART Medical Illustrations

Figure 6 Synaptic junction, showing neurotransmitters as black dots

Image: Courtesy LifeART Medical Illustrations

running of brain circuits, promoting communication among different parts of the brain (Figure 6).

Genetics and epigenetics

The processes that modify brain structures during pregnancy are predominantly determined by genetics, as is true for other organs such as the heart and lungs.

The modifications that occur after birth, on the other hand, are also influenced by the relationships that children establish with people around them, mainly caregivers, who are usually the child's father and mother. These bonds have the capacity to model, adjust and reorganise genetic tendencies. Transformations resulting from external influences are called epigenetics. (Mattick and Mehler, 2008); gene components may be activated, or not, by the child's interaction with adults. In this way, what is experienced in the first years of life determines the future of people and, therefore, the future of society (National Scientific Council on the Developing Child, 2010).

As it creates new neurons and connections, the brain at the same time also proceeds to eliminate connections that are not being used, in a process called 'pruning'. Pruning starts immediately after birth and extends until adolescence. This means that learning must be used, or the brain circuits corresponding to it may be eliminated.

Everything in its time

For each kind of learning to occur, there is a 'sensitive' or 'critical' period. These start at a very early stage (Nelson, 2000) – the critical period for auditory functions and other higher nervous activities such as emotions begins when the child is still in the uterus (Figure 7).

This is not to say that children who do not receive the right stimuli during the sensitive period can never acquire the function at all, as brain plasticity enables us to continue learning throughout our lives.Take language, for example. If, for some reason, the child lacks appropriate stimulation during the more sensitive period, that is, around the first 2 years, but this comes at a later age, the child may develop language skills, albeit perhaps with some difficulty in speech and school learning. If presenting stimuli too late in life may result in losses, presenting them too early – when the brain structure is not yet ready to learn and assimilate the new acquisition – may generate stress that disrupts emotional development (Bock *et al.*, 2005; Gunnar *et al.*, 2006, Shonkoff *et al.*, 2011).

Learning to cry and calm down

At birth, infants' brains are ready to start interacting with their surroundings. From their early relationships – almost always with parents, relatives and caregivers – the process of interaction creates a bond, known as attachment (Bowlby, 1990; Winnicott, 1990, Cypel, 2007). This is the point at which a child, initially totally dependent on the protection and affection of caregivers, begins the process of gradually acquiring autonomy, with their support.

Figure 7 Periods of functional development

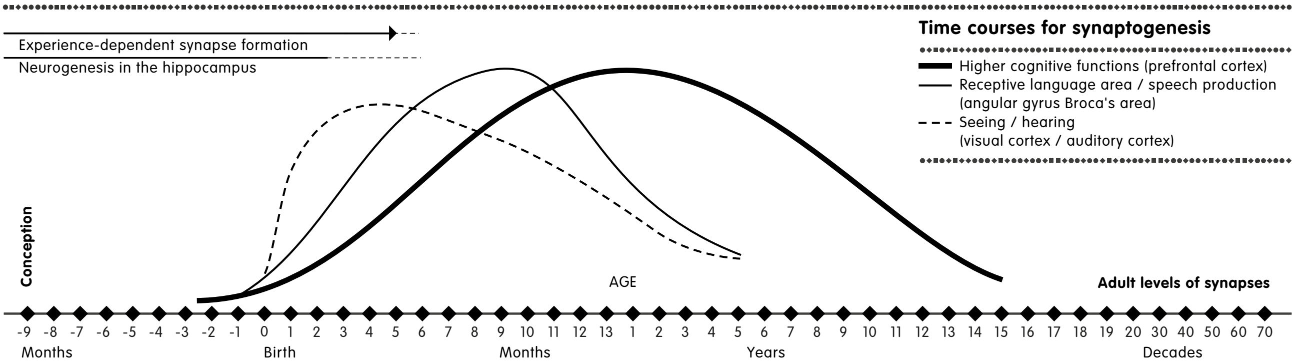


Image: Courtesy C. Nelson

Autonomy is gained progressively, showing specific characteristics at each age, and relying on learning and skills previously acquired, as well as emotions experienced at the time the learning occurred. The first things are learned right after birth, as evidenced by the fact that newborns, while totally dependent, are nonetheless capable of expressing hunger intensely. Crying may seem a simple reaction but it actually requires a complex internal process in the brain (Shore, 2002; Cypel, 2007). The amygdala, located in the temporal lobe, reacts to stimuli such as hunger which represent a risk to survival, generating insecurity and anxiety. Anxiety drives the hypothalamus–hypophysis–adrenal (HPA) axis, which stimulates the suprarenal glands to release hormones: adrenalin, noradrenalin and cortisol. These hormones make babies uncomfortable, accelerate their heartbeat, and make them blush and finally cry, warning the mothers that they are hungry or uncomfortable.

As time goes by, if infants realise that their needs are met, this information will be registered in their memory – they will become less anxious and will not request as many things. We might say that their amygdala is learning to 'behave better', as they feel reassured that their needs will be met and they will no longer feel so threatened or at risk. Over the months, a baby will learn to wait when the mother is not immediately available, without becoming desperate or feeling unattended.

Preparing for the future

Around 1 year old, infants are typically encouraged to use a small spoon and feed themselves. Around age 2 most children are capable of eating without being helped. Later, children are able to dress themselves, wait for their turn when playing, and so on. Through interaction with the environment around them, and with the active participation of family members, children develop the autonomy that one day will enable them to socialise adequately. Next comes school and the acquisition of more complex skills, along with the ability to deal with the natural adversities of life during the growing process.

This preparation starts very early in life, with the most elementary rules and limits. Therefore, it is key that the child be exposed to the frustrations that occur naturally. Dealing with routine, rules about what one can or cannot do, learning to wait and that one cannot always get what one wants immediately, are opportunities to prepare oneself for becoming a well-functioning part of society in the future.

All these gains from skills learned are represented in brain circuits – everything that is learned leaves a record in the brain, be it motor skills, emotional skills or any other kind of learning.

Babies begin developing skills and learning how to deal with environmental demands in accordance with their level of maturity (Cypel, 2007). By automatic imitation at first, they will gradually evolve and assimilate by becoming able to discern and absorb the rules, values and attitudes of the outside world – from putting on socks to tidying up toys and brushing teeth. Each of these actions is preparation for more complex objectives that will come up in adult life, such as organising a trip. To accomplish this task, adults need the capacity to organise, monitor the necessary steps, and put up with frustration, often having to make some corrections to reach the desired objective. This organisational capacity makes up what we call executive functions (Fuster, 1997; Barkley, 2001; D'Esposito, 2002; Cypel, 2006). Physically, the circuits of the executive functions are located in the prefrontal region, aided by the senses (sight, hearing, touch, smell and taste), which are located in different parts of the brain.

Children start to display executive functions from a very early age – their actions have a purpose which requires them to control several phases in the right sequence, correcting the course as needed and checking at the end to see whether the objective has been met. This process becomes progressively more complex, setting up the child's autonomy and promoting the development of the capacity to think.

Performing a task well requires individuals to keep an objective in mind during the sequence of actions that must be carried out before they achieve the goal. What we call 'working' or 'operating' memory is conceptually characterised by this capacity to focus on an ultimate objective. The lack of such capacity harms learning and personal development (Cypel, 2006). This can be observed when children ask for help with elementary activities that they should be able to carry out by themselves, such as getting dressed or doing homework – if they continue to have things done for them instead of being encouraged to learn to do things for themselves, they may not acquire the skills that they will need to acquire new learning and develop.

Conclusion

Adequate brain architecture structure during the first years of life is key to preparing individuals and providing the conditions to reach success in life. We might compare this process to a building where the floors are built one on top of another and the building's comfort will depend on the quality of the finishing details. While genetics provide the building materials, the environment and the child's personal experiences determine the success with which those materials are formed into a sturdy and pleasing construction. (Trevarthen and Aitken, 1994; Cypel, 2006).

It is fundamentally important that knowledge about this process should be disseminated in a clear and understandable way to professionals, public managers and opinion makers who can reach families. When parents are more aware of the importance of their role, they may be more likely to parent in ways that help their children's brains to develop. We should invest in seeking to offer the most favourable conditions for a family environment that fosters the building of an integral and integrated human being.

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