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# FOUNDATIONS OF COGNITIVE NEUROSCIENCE: A SYSTEMATIC MENTION OF THE NEUROBIOLOGICAL ASPECTS OF HUMAN COGNITION DEVELOPMENT

# FUNDAMENTOS DA NEUROCIÊNCIA COGNITIVA: UMA MENÇÃO SISTEMÁTICA DOS ASPECTOS NEUROBIOLÓGICOS DO DESENVOLVIMENTO DA COGNIÇÃO HUMANA

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## ABSTRACT

Cognitive Neuroscience is a multidisciplinary field that seeks to understand the complex relationship between the brain, mind, and behavior. It combines techniques and insights from areas such as psychology, neuroscience, computer science, and genetics to study how the brain processes information, makes decisions, and ultimately influences behavior. Recent advances in the molecular, genetic, computational (CompMod), mathematical (MathMod) and experimental areas have provided important improvements for basic and clinical applications in the fields of cognition (CS/CogF), as well as for new research protocols on learning and memory, spontaneous brain activity (SBA) and neurodevelopment (NDev), considering their relevance to normal cognitive apparatus.

**Keywords:** Neurodevelopment. Cognition. Learning. Research.

## RESUMO

A Neurociência Cognitiva é um campo multidisciplinar que busca entender a

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complexa relação entre o cérebro, a mente e o comportamento. Ele combina técnicas e percepções de áreas como psicologia, neurociência, ciência da computação e genética para estudar como o cérebro processa informações, toma decisões e, por fim, influencia o comportamento. Avanços recentes nas áreas molecular, genética, computacional (CompMod), matemática (MathMod) e experimental têm proporcionado importantes melhorias para aplicações básicas e clínicas nas áreas de cognição (CS/CogF), bem como para novos protocolos de pesquisa em aprendizagem e memória, atividade cerebral espontânea (SBA) e neurodesenvolvimento (NDev), considerando sua relevância para o aparato cognitivo normal.

**Palavras-chave:** Neurodesenvolvimento. Conhecimento. Aprendizado. Pesquisar.

## 1. INTRODUCTION

The foundations of Cognitive Neuroscience constitute the basic concepts and relevant biological and psychological knowledge, essential to open paths for the analysis and understanding of complex neural mechanisms that are related to learning and cognitive functions. It is also important to generate new types of studies and approaches in research on the brain and on its integrated learning processes, as well as stablishing parameters to carry out more advanced and methodologically more sophisticated experimentais procedures.

This work presents the main fundations of science that are involved in current research for the improvement of brain and neurodevelopment studies, along with the technological resources used to carry them out.

## 2. NEURAL ARCHITECTURE

### 2.1. FROM SIMPLE TO COMPLEX ORGANIZATION

Cognitive Neuroscience studies the intricate structure and connectivity of the brain, examining how different regions are organized and communicate with each other. Neurodevelopment refers to the growth and development of the nervous system, particularly the brain, from gestation to adulthood. The Nervous

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System (NS) development includes the growth and maturation of neurons, synapse formation, and the stablishment of neural circuits.

The development of *Neural Architecture* spans the early stages of brain and NS development, from embryonic processes through childhood and throughout adolescence. Crucial concepts in neurodevelopment are as follows:

1. *Neural development starts early*: The foundation of the nervous system forms during *embryonic development*, with the neural tube forming the basis for the brain and spinal cord. (SANES *et al.*, 2011).

2. *Neuronal proliferation*: Once the *neural tube* is formed, rapid cell division occurs, leading to the production of billions of neurons (JESSBERGER *et al.*, 2011; PURVES *et al.*, 2011).

3. *Neuronal migration*: Neurons then migrate to their specific destinations within the developing brain and spinal cord, guided by chemical signals (LaBONNE and MOODY, 2018).

4. *Neuronal differentiation*: During this stage, neurons develop some distinct characteristics and start forming connections with other neurons, forming networks (BANKER and GOSLIN, 1998).

5. *Synaptogenesis*: Synapses, the connections between neurons, are formed and strengthened during this process, allowing for the *transmission of electrical and chemical signals*. (LEVY *et al.*, 2012).

6. *Myelination*: This process involves the formation of a fatty substance called *myelin* around the axons of neurons, which *helps to increase the speed and efficiency of electrical signals*. (MACKLIN and CASACCIA, 2004).

7. *Critical periods*: Certain stages of neurodevelopment are considered *critical periods*, during which environmental factors and experiences have a significant impact on brain development (TORTOSA, 2011). For example, language development in early childhood is strongly influenced by exposure to language during this period.

8. *Plasticity*: The brain is highly plastic, meaning it has the ability to change and adapt throughout life. This process is most pronounced during early development but continues to some extent throughout adulthood. (FIELDS and DECETY,

2007; TORTOSA, 2011).

Understanding neurodevelopment is crucial because disruptions or abnormalities in this process can lead to various developmental disorders or neurological conditions (ALEXANDER, 2008; FIELDS and DECETY, 2007; TORTOSA, 2011). This is why the study of neurodevelopment is so important in neuroscience research, specially in cases of processes involved in neural development from the embrionic stages to the postnatal period, highlighting the key and fators that influence the formation and maturation of the brain, reaching the biological complexity of the NS architecture (BEAR, 2015).

### 2.2. CORTICAL DEVELOPMENT AND NEURONAL ORGANIZATION

During normal neurodevelopent, *cortical brain development* occurs as a complex process through which the cerebral cortex develops and matures over time. This process includes the formation and organization of *neurais connections*, as well as the acquisition of *functional specialization* in different regions of the cortex (GROVE, 1988).

During the process of *embryonic development* (MEYER *et al.*, 2000) *and postnatal development* (LeROY, 1967), the cortical layers in the human cerebral cortex form according to a peculiar timeline:

*1. Preplate formation*: Around 7 to 8 weeks of gestation (future layers I and II).

*2. Cortical plate formation*: Around 8 to 24 weeks of gestation, the preplate differentiates into the cortical plate (future layers II to IV).

*3. Inside-out layering*: Layer VI, the deepest cortical layer, is formed first (by around 12 to 16 weeks of gestation, layer VI is mostly established).

4. *Layer V development:* Following the formation of layer VI, the development of layer V begins around 16 to 20 weeks of gestation.

5. *Upper layers development:* Layers IV, III, and II develop later in the process, with layer IV typically forming between 20 to 24 weeks of gestation, followed by layers III and II between 24 to 32 weeks.

Each cortical layer contains specific types of neurons that contribute to the functioning of the cortex. Knowledge of these cytoarchitectural structures is important to determine clinical procedures in medicine (especially Neurology) and Clinical Neuropsychology, due to their neuroanatomical organization and histological distribution in the brain (BHUYIAN *et al.*, 2014). The layers and types of neurons found in each are:

1. *Layer I (Molecular Layer):* This layer is the most superficial cortical area of the brain and contains few *cell bodies*. It primarily consists to *axons*, *dendritic processes*, and the *projections of neurons* from other layers.

2. *Layer II (External Granular)*: This layer contains *small pyramidal neurons*, also known as *granule cells*. These neurons receive *inputs* from other cortical regions and relay information to subsequent layers.

3. *Layer III (External Piramidal)*: This layer contains primarily *medium-sized pyramidal neurons*. These neuronal cells receive *inputs* from other cortical and subcortical areas and transmit information to these regions.

4. *Layer IV (Internal Granular)*: Contains *granule neuronal cells*, similar to layer II. However, layer IV is more prominent in sensory areas of the cortex, where it receives *direct input* from thalamic nuclei conveying sensory function.

5. *Layer V (Internal Piramidal)*: Contains *large pyramidal neurons*. These neuronal cells send *long-range outputs* to other cortical areas or subcortical structures, playing a crucial role in motor control.

6. *Layer VI (Multiform Layer)*: Contains a *heterogeneous mixture of neurons*, including piramidal neurons and inhibitory interneurons. They sends *feedback connections* to the thalamus, modulating sensory information processing.

The human cerebral neocortex has a topographical distribution that in integrative work generates patterns of activation. The Frontal Lobe (FL) is the most involved in cognitive functions (FUSTER, 2002). Along with the Parietal Lobe (PL), Temporal Lobe (TL) and Occipital Lobe (OL), the *frontal cortex* can generate and control complex learning and behavior. One particular area of the brain in all species involved in cognitive and behavioral processes is the Prefrontal Cortex (PFC).

Korbinian Brodmann *apud* Murray *et al.* (2016, pp. 22-24) studied different species of animals to understand the functions of the *frontal cortex*. Brodmann stablished that the PFC in the cat constitutes 3.5%¨of the brain, 12.5¨% in dogs, constitutes 11.5% in monkeys, around 17% in chimpanzees, and 29% in humans (BRODMANN, 1905/1908/1909). In the human brain, with a larger cortex size, cognitive functions are more coordinated and complex in the PFC, such as somatic function, eye movements, planning, self-monitoring, intellectual activity, emotional regulation, language control, social behavior and decision-making.

## 3. COGNITIVE PATTERNS OF NEURODEVELOPMENT (NDev)

### 3.1. FUNCTIONS OF THE COGNITIVE SYSTEM (CS)

The *cognitive system* (CS) constitutes a complex network of cognitive processes and functions that work together to enable mental activities such as perception, attention, memory, language, problem-solving, and decision-making. In terms of scientific discipline, it can also be understood as a multidisciplinary field, including Neuroscience, Cognitve Science, Artificial Intelligence, Computer Science, Linguistics, Anthropology and Psychology (WILLINGHAM, 2014).

The CS involves the interaction of various cortical and subcortical brain regions and processes, including *sensory input*, information processing, and *output*. It includes both conscious and unconscious mental processes and plays a significant role in shaping our perception of the world, interpreting information, and guiding behavior. The normal processes of human intelligence, coordination and motor development according to different ages is shown in Table 1.

Human *cognifive functions* (CogF) is described here through the following concepts:

1. *Attention and perception*: Neuroscience investigates how the brain selectively processes and interprets sensory information, shaping our perception of the world. In this context, one of the most important human cognitive abilities is the *relationship between attention and social interactions*. This is why correctly understanding the intricate intersection of attention and perception in social context is highly important (POSNER, 2012).

2. *Memory and learning*: Researchers explore how the brain encodes, stores, and retrieves information, as well as how learning processes affect *brain plasticity*. In his book *In Search of Memory: The Emergency of a New Science of Mind* published in 2006, Eric Kandel explores the *biological and psychological foundations of memory and learning*, including groundbreaking research and discoveries related to memory storage and synaptic plasticity (KANDEL, 2006).
3. *Language and communication*: Cognitive Neuroscience investigates how the brain processes and produces language, studying the neural basis of speech, reading, comprehension, and other language-related functions. This line of research explores the *innate language abilities of humans*, the structure of language, and how it is acquired and processed in the brain (PINKER, 2000).
4. *Executive functions*: This refers to *higher-level cognitive processes* involved in decision-making, problem-solving, planning, and self-control. In addition to these, research in Neurosciences in this line is dedicated to understanding the *development of executive functions*, their importance in various domains such as education and mental health, and strategies for improving executive functions skills (DIAMOND, 2013).
5. *Emotion and social cognition*: Brain and mind researchers explore how the brain processes emotions, social interactions, empathy, and theory of mind, shedding light on the *neurological basis of human behavior in social contexts*. This line of study is one of the most important in experimental fields such as Neurosciences, Cognitive and Brain Sciences, considering the influence of emotion on social behavior, impression formation, emotional contagion, and decision making. It involves various aspects of how emotions influence social perception, judgement and human interactions (FORGAS, 2013).

Cognitive Neuroscience aims to understand the neural mechanisms underlying these functions. The CS and/or the cognitive functions (CogF) are often studied in Cognitive Psychology together to Neuroscience to understand how individuals acquire, process, and utilize information. Processing of information in the brain refers to the *various cognitive processes involved in receiving, interpreting, and responding to sensory information* (POSNER, 2012).

Fundamental cognitive processes are key to the brain development, through complex patterns such as the mechanisms underlying attention and how it relates to social interactions and information processing in the brain.

**Table 1.** Normal cognitive development at ages from childhood to adolescence.

| COGNITIVE PATTERN | AGE | COGNITIVE CHARACTERISTICS |
|---|---|---|
| **Intelligence and learning development** | 0-5 years | During this period, children´s brains are rapidly developing laying the foundation for future learning and cognitive abilities. |
| | 6-11 years | This stage is characterized by significant cognitive growth and the acquisition of more advanced academic skills. |
| | 12-18 years | This period is marked by considerale cognitive development, including the growth of abstract thinking decision-making , and planning for the future. |
| **Coordination and motor development** | 0-12 months | Babies begin to develop basic gross motor skills, such as rolling, sitting, crawling, and eventually walking. |
| | 1-3 years | Toddlers continue to improve their gross motor skills, become more stable on their feet and developing the ability to run, jump, and climb. |
| | 3-5 years | Refine their coordination and balance further, allowing them to engage in more complex physical activities. |
| | 6-12 years | Continue to improve their motor skills, becoming increasingly coordinated and precise in movements. |

References: BLAKEMORE (2019); GARDNER (1983); GESELL (1946); PIAGET (1950/1952); SIEGEL (2012).

## 3.2. NEURAL PROLIFERATION AND SYNAPTOGENESIS: BETWEEN NORMAL AND ABNORMAL NEUROLOGICAL CONDITIONS

The concept of *neuronal proliferation*, also known as *neurogenesis*, refers basicaly to the process of generating new neurons within the brain. This line of study extends from the understanding of *prenatal neurological formation*, passing through the long process that goes from birth to childhood, and, arriving in adolescence, with a mechanism of *neurogenesis* that is not yet definitive. Some facts about neuronal proliferation are presented below:

1. *Adult neurogenesis*: Traditionally, neurogenesis was believed to occur only during prenatal development. However, researchers have now discovered that neurogenesis also takes place in specific regions of the adult brain, such as the *hippocampus* and the *olfactory bulb*. This process includes the underlying cellular and molecular mechanisms, the regulation of this process, and its functional implications. Additionaly, It is crucial for adult neurogenesis and its significance in brain plasticity and cognitive function (KEMPERMANN, 2011a).

2. *Hippocampal neurogenesis*: The *hippocampus*, a brain region associated with learning and memory, exhibits significant levels of neurogenesis throughout adulthood. New neurons in the *hippocampus* play a crucial role in processes such as spatial learning, pattern separation, and memory formation. As for the functional significance of this process, its regulation, and the impact it has on mental health, neurological disorders, and brain diseases, the importance of this *cytological balance* is vital for the brain functioning of human cognition (SAHAY, 2016).

3. *Factors influencing neurogenesis*: These factors can include both *intrinsic factors* (such as genetics and cellular mechanisms) and *extrinsic factors* (such as environmental stimuli and lifestyle choices). This means that several factors influence *neuronal proliferation*: Physical exercises, environmental enrichment, reading and learning have been found to promote neurogenesis. Conversely, factors like stress, aging, and certain psychiatric conditions can decrease neurogenesis (KEMPERMANN, 2011b).

4. *Neurogenic niches*: Neurogenesis occurs within specialized regions of the brain known as *neurogenic niches*. These provide an *optimal microenvironment* for neuronal *stem cells* to proliferate and differentiate into mature neurons. This specialized microenvironments within the brain are also important to support the maintenance of neural stem cells and their progeny (BUYLLA, 2013).

5. *Neural stem cells*: Are the genetic elements responsible for neurogenesis. These cells have the ability to *self-renew and differentiate into various types of*

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*neurons.* Understanding the properties and mechanisms of *neural stem cells* is crucial to unlocking the full potential of neurogenesis. Additionaly, the knowledge of these properties and mechanisms constitutes the basics for various experimental techniques and protocols used in the study of neural stem cells, as well as provides resources into the isolation, culturing, and characterization of *neural stem cells*, including their potential applications in *regenerative medicine and neurobiology researh* (SALLY, 2008).

6. *Function and integration of new neurons*: New neurons generated through neurogenesis need to integrate into the existing neural circuits to function properly. Adult neurogenesis have implications in various neurological and psychiatric disorders, due to the functional integration of *newly generated neurons* in the adult brain and how it relates to brain function and plasticity (JESSBERGER *et al.*, 2011).

7. *Implications for brain repair and mental health*: Research on neuronal proliferation holds potential implications for brain repair and mental health. Enhancing neurogenesis can help control *brain injuries* or *neurodegenerative disorders* (Alzheimer's and Parkinson's disease, epilepsy, Huntington´s disease, schizophrenia, etc). Amelia J. Eish (2002), in *Adult neurogenesis: Implications for psychiatry*, explores the field of adult neurogenesis and its implications for brain health and mental disorders. Other complex neurobiological aspects are the mechanisms underlying adult neurogenesis and how it relates to psychiatric disorders (EISCH, 2002).

Additionally, targeting neurogenesis may provide new avenues for treating mental health conditions such as depression and anxiety. It is important to note that the field of neuronal proliferation is continually evolving, and ongoing research aims to further uncover the mechanisms and potential applications of neurogenesis. Normal patterns of neurogenesis during the learning process were obtained experimentally with rats *in vivo*, as shown in Figure 1.

According to Levy *et al.* (2012), the concept of *synaptogenesis* refers to the process by which the connections between neurons, called *synapses*, are formed in the developing brain. It is a crucial aspect of brain development and occurs mainly during early developmental stages, although it continues throughout life to a lesser extent. These concepts are highly important for understanding the processes of development of points where information is transmitted from one neuron to another, as well as offering the basis of regulatory patterns within molecular dynamics, cellular mechanisms, and provides the right path for experimental techniques (LEVY *et al.*, 2012).

During *synaptogenesis*, neurons extend their axons and dendrites, which are the long projections of the nerve cells. These axons and dendrites grow and form connections with other neurons, forming synapses. Synapses are the specialized junctions where communication between neurons takes place, allowing the *transmission of electrical and chemical signals*. The formation of synapses is influenced by various factors, such as genetic instructions, neuronal activity, and environmental stimuli (FIELDS and DECETY, 2007; TORTOSA, 2011). Neurons undergo a process called *axon guidance*, where *they are guided towards their target cells by molecular cues* (PASTERKAMP, 2007).

Once the appropriate connections are established, the synapses undergo refinement and strengthening through a process called *synaptic plasticity* (TORTOSA, 2011). Synaptogenesis plays a critical role in shaping the structure and functions of the brain. It establishes the neural circuits that underlie various cognitive functions such as learning, memory, perception and motor control.

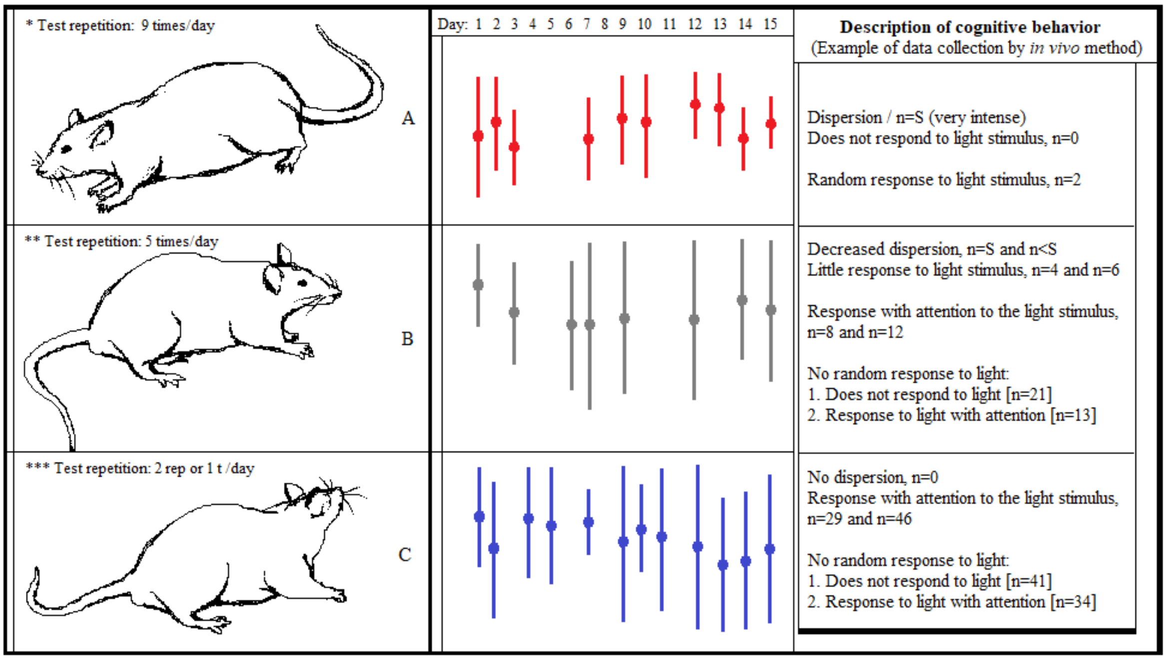


**Figure 1.** Example of three situations of brain research during an experiment of 45 days with laboratory animals, focusing learning processes that occur in normal patterns of *neurogenesis* and *synaptogenesis*. **A.** Greater dispersion and scape fo the light stimulus. Weak response: n=0 and n=2 (Graphic registration remains red between maximum and minimum); **B.** Decreasing dispersion (lower entropy: n=S and n<S) and more response to light: n=4 and n=6. No random response. Answer carefully: n=13 (Graphic registration goes from red to gray); **C.** No dispersion (n=0), low entropy (n<<S) and greater response to light with attention: n=29 and n=46 (Graphic registration changes from gray to blue). [*]: *Greater repetition*; [**]: *Average repetition*; [***]: *Low repetition*. (Measurements according to *spontaneous brain activity* - SBA). [Image Credit: IPSTech Maicon Aliaga Project, *Art and Science: The Brain - Paper II*, 2017 (Updated version, 2021).].

Deep understanding of synaptogenesis is important in Neuroscience research and has significant implications for addressing different cases of neurodevelopmental disorders (NDD), psychopathologies, personality variants, neurodegenerative diseases and, consequently, for the potential improvement of therapies aimed at promoting the development and healthy brain function. Some abnormal conditions that can occur during development can negatively affect the neurological process of neurogenesis and synaptogenesis, which can result in neurodegenerative diseases.

## 4. APPLICATIONS IN BRAIN RESEARCH

### 4.1. COMPUTATIONAL MODELING (CompMOD)

Cognitive Neuroscience often employs *computational models* to simulate

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and understand complex cognitive processes, helping to generate hypotheses and make predictions about brain function. This type of aproach of technological resources in the field of Cognitive Neuroscience can be applied in various studies of cognitive processes, as well as to help us understand the mechanisms underlying brain function.

According to O'Reilly (2016) of Massachusetts Institute of Technology (MIT), this research model can be advanced *through the integration of computational models and empirical studies* (O'REILLY, 2016). Different models may employ different parameters and methodologies based on their specific goals and assumptions. Some of them can be considered as follows:

*1. Neuron models:* I. Hodgkin-Huxley Model - of the electrical activity of neurons (HODGKIN and HUXLEY, 1952); II. Integrated and Fire Model - that describes neural dynamics (GERSTNER and STOCKS, 1996).

*2. Synaptic transmission models:* I. Alpha Function Model - for the time course of synaptic conductance (GAZZANIGA *et al.*, 2008); II. Spike-Timing-Dependent Plasticity (STDP) - based on the relative timing of pre and postsynaptic spikes (GERSTNER *et al.*, 1996).

*3. Network architecture models:* I. Small-World Networks - characterized by high clustering coefficient and short average path lenght (WATTS and STROGATZ, 1998); II. Scalle-Free Networks - with a power-law distribution of node degrees (BARABÁSI and ALBERT, 1999).

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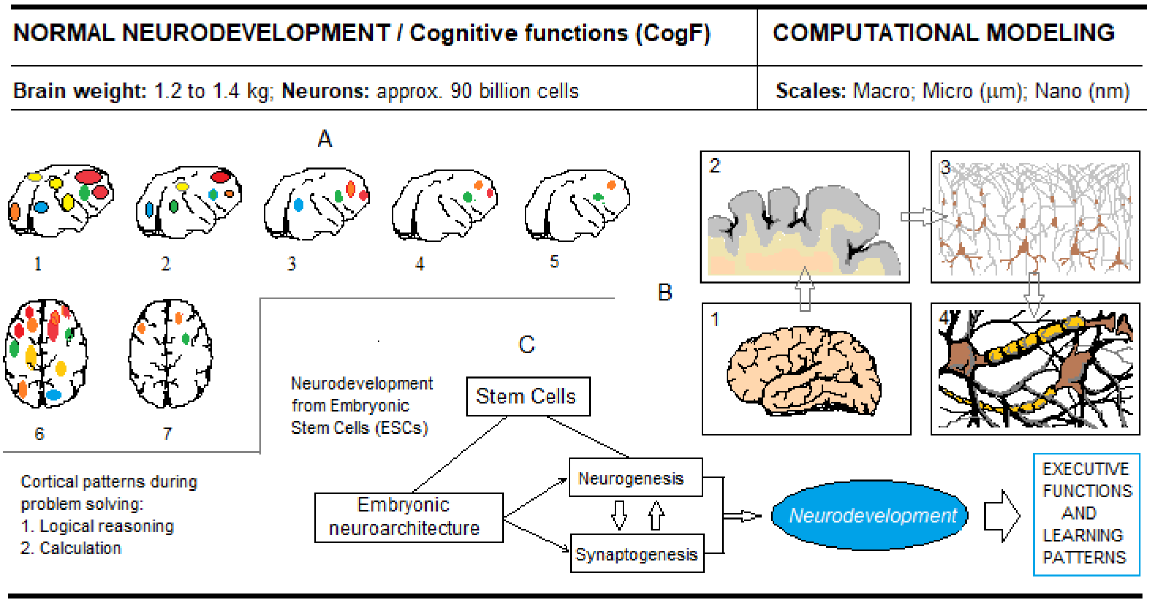


**Figure 2.** Illustration of Normal Neurodevelopment by Computational Modeling. **A.** 1 and 2: Cortical patterns associated with two *major states of doubt during early mathematical problem solving*; 3 and 4: Cortical patterns in problem *solving process*; 5. Cortical pattern when *problem solved*; 6. Maximum entropy; 7. Minimum entropy. **B.** *Multiscale modeling* (MSM): 1. Brain (larger macrostructure); 2. Gray and white parts of the cerebral cortex (minor macrostructure); 3. Cortical layers (larger microstructures); 4. Cortical neurons and axons (smaller microstructures). **C.** *Diagram of Neurodevelopment* from Embryonic Stem Cells (ESCs).

### 4.2. MATHEMATICAL MODELING (MathMOD)

In Neuroscience, various mathematical models are used to study different aspects of brain functioning. Some of these models are known for their current applications and their goals in science:

*1. Descriptions of the spaciotemporal dynamics of groups of neurons:* I. Neural fields theory; II. Dynamics of neural fields (BRESSLOFF, 2006/2011).

*2. Descriptions of macroscopic brain activity and neuronal behavior:* I. Neural mass models (ERMENTROUT and TERMAN, 2010); II. Neural mass model of firing rate activity in the neocortex (NUNEZ, 1974).

*3. Mathematical modeling of spiking neurons and the computation performed by neurons:* I. Spiking neuron models: II. Biophysics of computation (GERSTNER and KISTLER, 2002; KOCH, 1999).

*4. Mathematical foundations of artificiais neurais networks:* I. Neural networks and Deep Learning (GOODFELLOW *et al.*, 2016); II. Theoretical Neuroscience and computational applications in neurais systems (DAYAN and ABBOTT, 2001).

An application in the experimental field, studying *learning and behavior*, the *Learning Pattern Theory* can be understood by the *reduction of entropy accordind to the specific cortical activity of the brain* (according to *spontaneous brain activity,* SBA). In this analytical model, the equation allows checking events in $X_n$ and $Y_n$. So for all $X$ the variables $x_1, x_2, x_3, \ldots x_n$ are the differences within a whole sequence of *learning pattern* variables in $\sigma$(Learning); likewise for all $Y$ the variables $y_1, y_2, y_3, \ldots y_n$ are the differences within the sequence of variations of *behavioral changes* in $\sigma$(Behavior), observed during the experiment. Associated with the time of each variable, the most significant activity takes more time:

$$\sigma(\text{Learning}) = X_n \{x_1, x_2, x_3, x_4, \ldots x_n\}, t\,(a, b, c, \ldots n),$$
$$\sigma(\text{Behavior}) = Y_n \{y_1, y_2, y_3, y_4, \ldots y_n\}, t\,(a, b, c, \ldots n).$$

The relationship between the times of events assoc iated with variables $X_n$ (Learning) and $Y_n$ (Behavior) is given by:

$$\Delta S(t){:}(Lea/Beh) = \sum_{i=1} nt / (X_n, Y_n).$$

Considering only the *learning pattern* $\sigma$(Learning), when a variable is unique in a sequence the event in time is computed starting with |1| (information = *learning*). And, when repeating in this sequence the event in time is computed with |0| (no information = *entropy*). Below, for the learning sequence we have:

$$\sigma(\text{Learning}) = X_n{:}\ [x_1\,(|1|0|0|),\ x_2\,(|1|0|),\ x_3\,(|1|0|0|0|),\ x_4\,(|1|0|0|)],$$

with $t$ (times) of the individual sequences $a = 16$ min., $b = 12$ min., $c = 4$ min., and $d = 6$ min., *the entropy of 40 minutes of in vivo observation based on the time spent for the learning of a task* in four situations, ($x_1$(3); $x_2$(2); $x_3$(4); $x_4$(3)), will be:

$$\Delta S(t){:}(Lea) = \sum nt / X_n = (16/3) + (12/2) + (4/4) + (6/3) = 14.3 \text{ minutes.}$$

This means that the time taken to learn determines *how much entropy for cortical activity relative to a task was required in each sequence*, which in this specific case, 14.3 minutes was the minimum useful time to generate a cognitive pattern in the rat brain during the motor task. The less minimum time used, the more entropy is happening. And the more time, the less entropy and the more learning (the more application of time, the more cognitive activity there is).

**Table 2.** Application of Learning Patterns Theory representing entropy reduction with longer learning time during three e xperiments (120 minutes).

| **TEST** (n) | **TASK LEARNING PATTERN** σ(Learning) | **COMPUTING USEFUL TIME** *t* (*a*, *b*, *c*,...), T(t): 40 min. | **ENTROPY** *ΔS(t):(Lea)* |
|---|---|---|---|
| *Exp1* | *Xn*: [$x_1$(4), $x_2$(3), $x_3$(5)] | a:12; b:16; c:12 | 10.73 [++++] |
| *Exp2* | *Xn*: [$x_1$(2), $x_2$(4), $x_3$(4), $x_4$(3)] | a:20; b:8; c:7; d:5 | 15.42 [++] |
| *Exp3* | *Xn*: [$x_1$(4), $x_2$(3), $x_3$(5), $x_4$(4), $x_5$(2)] | a:12; b:16; c:6; d:3; e:3 | 11.78 [+++] |

Table legends: [++++]: *Greater entropy*; [+++]: *Average entropy*; [++]: *Low entropy*.

Along with computational models, algorithms, axioms and mathematical constructs are very efficient ways to formulate predictable theories and generate experimental protocols and models in dynamical systems and Neuroscience (ERMENTROUT, 2002). During a series of laboratory tests, data is recorded in a secure and controlled manner, including corrections, calibrations and standard deviations. Based on certain previously verified electrophysiological conditions, as well as the availability of technological resources, the tests can be adapted to optimize the work, both of the neurobiological data and the margins of possible errors in the methods used.

## 5.FINAL CONSIDERATIONS

The work presented here constitutes a review text, with fundamental data and canonical theories of the disciplines that describe cognitive functioning at the neurobiological level. Based on extensive studies, protocols and methods, new discoveries and modern research in cognitive sciences have been implemented with cellular and genetic models, in addition to computational and mathematical techniques. The advances of these applications represent real horizons for the improvement of therapies, guidelines in education and psychology, diagnostic and medical treatment of neurological diseases that affect human cognition.

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