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Review Article

How Does the Human Brain develop? Insight of The Modern Neuroscience

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Abstract:

Throughout a significant portion of the 20th century, predominant theories of brain development were largely deterministic. It was believed that brain development follows a predetermined blueprint that is somehow innately encoded within the organism. Modern theories offer a markedly different perspective on both inheritance and brain development. Firstly, we do not inherit blueprints or plans; rather, we inherit genes and the cellular mechanisms required for their expression. Genes contain vital information for the synthesis of proteins, but they do not dictate biological processes or developmental results; the initial cells possess the components necessary for protein synthesis based on the information encoded in the nucleotide sequences of genes. Secondly, brain development is a dynamic process: the biological condition of the brain at any given moment results from developmental processes that involve a complex interaction between genes and an ever-growing array of environmental influences—from local cellular activities to external factors. In the realm of science, models are significant. They embody fundamental assumptions regarding how phenomena can occur, thereby shaping the types of inquiries we pursue, the experiments we design, the therapies we create, and the educational programs we establish. The dynamic model of brain development explains powerful neurobehavioral effects that deterministic models simply cannot accommodate.

Key words: brain neuroplasticity; neurobehavioral; neuroscience

Introduction

The mature human brain comprises approximately 85 billion neurons that establish trillions of connections with other neurons, forming the basis of all human thought, emotion, action, and behavior [1]. One of the most essential inquiries in contemporary neuroscience is how this remarkably intricate biological system comes into existence. In essence, how does the human brain evolve?

Early theories of brain development were predominantly deterministic, focusing on the notion that development follows a predetermined blueprint that is somehow innately encoded within the organism. Modern theories offer a markedly different perspective on both inheritance and brain development. Biological inheritance encompasses two critical components: the first is DNA, which consists of nucleotide sequences (the genes) that act as a template for protein synthesis. Proteins, rather than genes, are the active participants in all developmental processes. Nevertheless, DNA has never been inherited in isolation. The inheritance of DNA invariably includes the second inherited component, the first cell, which contains both the DNA and the cellular machinery necessary to transcribe the information in the DNA into proteins. On its own, DNA is inactive. It is only through the transformative processes of DNA transcription and RNA translation that the information contained in the DNA becomes functional.

Therefore, at the moment of conception, the child inherits both the DNA and the initial environment (the cell) that collectively provide the essential tools for all subsequent development, including brain development (2-4). Neither genes nor environmental factors dictate outcomes. The biological condition of the organism at any given time is the result of developmental processes that involve a complex interplay among intricate cascades of gene expression interacting with influences from an ever-growing array of environmental factors—from local cellular events to external influences [5].

The development of the brain occurs over an extended duration and entails the intricate interplay of molecular (genetic), cellular, and environmental systems and components [6,7]. Furthermore, it is a progressive process: structures and systems that arise at a certain stage of development frequently lay the groundwork for the emergence of subsequent systems. This essay aims to examine three fundamental concepts of this dynamic process: neural plasticity, progressive differentiation and commitment, and sources of developmental constraint. Each of these subjects utilizes examples that demonstrate brain development as progressive, dynamic, and adaptive, rather than being innately predetermined.

Brain neuroplasticity

Essentially, the brain exhibits adaptability. It modifies itself in response to various biological or environmental factors. The concept of neural plasticity encompasses this extensive adaptability across nearly all aspects of the neurocognitive system, ranging from molecular changes to behavioral adjustments [7-8]. Neural plasticity is active throughout the typical development of the brain. For instance, it is evident in the neural networks responsible for face processing (refer to Haist and Anzures, Functional development of the brain's face-processing system, WIREs Cogn Sci, and also in the collection How We Develop). In this context, it is noted that children engage a broader array of brain structures compared to adults. As individuals gain expertise in face processing, the neural networks undergo pruning, resulting in the engagement of only the most efficient and effective components of the face network.

The manifestations of neural plasticity are particularly pronounced in pathological conditions (see D'Souza and Karmiloff-Smith, Neurodevelopmental disorders, WIREs Cogn Sci, and also in the collection How We Develop). A variety of neuropathological occurrences can influence developmental trajectories and consequently modify fundamental patterns of brain organization. These modifications illustrate the inherent neuroplasticity of the immature brain as it adapts to the repercussions of neural damage. While plasticity is most apparent in younger organisms, it is also observable, albeit to a lesser extent, in the adult brain (see Power and Schlaggar, Neural plasticity across the lifespan, WIREs Dev Biol, and also in the collection How We Develop). Numerous studies have shown that the mature brain is capable of reorganizing itself (at least within localized brain regions) in response to injury (9-10). Therefore, at every stage of development and at all levels of the neural system, the ability to adapt is crucial for the functional viability of the organism. Indeed, the inability to adapt can lead to disastrous outcomes. Consequently, neural plasticity is a fundamental aspect of brain development [11].

Gradual refinements and commitments of the neural system

Progressive differentiation and progressive commitment are two essential and interrelated components of brain development [12]. Progressive differentiation pertains to the gradual refinement of the neural system, which includes the specialization of various cell types, the formation of connection patterns, and the establishment of diverse functions within neural networks (refer to Darnell and Gilbert, Neuroembryology, WIREs Dev Biol, also found in the collection How We Develop). At the onset of development, the embryo starts as a relatively undifferentiated mass of cells. In the third week post-conception, molecular signaling among subgroups of cells triggers a transformation in one group, leading to their differentiation into neural stem cells. These neural stem cells are also referred to as neural progenitor cells, as they are responsible for generating all other neurons and numerous support cells (see Jernigan and Stiles, Construction of the human forebrain, WIREs Cogn Sci, also included in the collection How We Develop). The differentiation process of neural stem cells incorporates a spatial aspect that is vital for establishing the fundamental functional organization of the embryo. Alongside the signaling that encourages differentiation, additional signaling prompts neural stem cells in rostral areas to develop into forebrain progenitors, while cells located more caudally evolve into spinal and hindbrain progenitors—subgroups of neural stem cells that will eventually form distinct neuron populations in the forebrain, hindbrain, and spinal cord. The intricacy of progressive differentiation indicates a significantly different paradigm of brain development compared to more deterministic models.

Progressive commitment is intricately linked to and complements progressive differentiation, reflecting processes that are associated with the stabilization of neural elements and systems. As previously discussed, developing systems demonstrate significant plasticity and the ability to adapt to diverse signals and contingencies. However, this plasticity diminishes as development progresses, as various neurocognitive elements become increasingly committed to specific systems [13]. This phenomenon of progressive commitment is effectively illustrated by studies on 'monocular deprivation,' where an eye is deprived of light stimulation during early development (refer to Power and Schlaggar, Neural plasticity across the lifespan, WIREs Dev Biol, also included in the collection How We Develop).

These studies were conducted to investigate the impact of early deprivation on a critical aspect of primary visual cortex organization, namely the ocular dominance column (ODC). ODCs arise because the neural inputs from each eye are clustered within the visual cortex, resulting in distinct banding patterns. In the monocular deprivation studies, one eyelid of young monkeys was sutured shut. In the youngest monkeys, this deprivation period led to reorganization within the ODCs. Specifically, the bands linked to the deprived eye significantly shrank, while the bands associated with the active eye expanded into the territory of the deprived eye. These findings clearly illustrated input-driven plasticity in the developing brain. Importantly, the magnitude of this effect diminished with longer delays in the onset of deprivation. The most pronounced effects of deprivation were noted in the youngest monkeys (approximately 6 weeks old); by the age of 1 year, no effects of deprivation were observable. This exemplifies the principle of progressive commitment. Progressive differentiation and commitment represent complementary aspects of brain development. They illustrate the crucial equilibrium between the capacity for adaptation and the necessity for stability in functional systems. The two constructs express the temporal nature of brain development. At every level of the neural system, differentiation combined with commitment seems to be the fundamental principle of brain development.

Limitations or restrictions on brain development

From the very start, brain development is shaped by both intrinsic factors, which include molecular signals from gene expression, cell–cell interactions, and system activation, as well as extrinsic factors that come from external inputs to the organism. Neither of these factors operates independently to dictate developmental outcomes. Instead, they collaborate as part of a complex and dynamic system that aids and directs brain development. This model of neural development is rooted in the developmental process itself, with each phase being influenced by numerous signals emerging from various levels of the developing system. Indeed, one might reasonably question whether such a model is overly dynamic. There are numerous degrees of freedom within these intricate, interactive signaling pathways, but if there is no specific mechanism to determine a particular outcome, how is it that development progresses with such consistency to create species-typical organisms? The answer to this inquiry lies in the understanding that while development is dynamic, it occurs within the framework of three significant constraints that stem from three main sources: genetics, environment, and time. Genes serve as essential molecular instruments. They supply resources necessary for the synthesis of specific proteins that are crucial for various key developmental processes. Each species, as well as each individual, possesses a unique set of genes that has been accumulated throughout evolutionary history. Although genes do not dictate developmental pathways, their presence at the appropriate time and in adequate amounts imposes significant limitations on the progression of development. For instance, during the initial patterning of sensory and motor cortical regions, complementary concentration gradients of various molecular signals create the foundational organization (refer to Figure 5 in Power and Schlaggar, Neural plasticity across the lifespan, WIREs Dev Biol, also included in the collection How We Develop). For example, Pax6 is expressed in a gradient that is most intense in the anterior sections of the developing neural plate, gradually diminishing in concentration towards the posterior regions. Conversely, Emx2 exhibits an opposing expression pattern.

The specification of motor, somatosensory, and visual areas within the neural plate relies on the precise combination of these two signaling molecules at specific concentrations (i.e., a high level of Pax6 combined with a low level of Emx2 results in the formation of motor areas, whereas a high level of Emx2 with a low level of Pax6 leads to the development of visual areas). In experimental research involving rats, the expression level of one of the two gene products was modified to reduce its expression gradient, thereby changing the exact combination of signals received by cells in specific regions of the neural plate. Consequently, the patterning of the cortex was altered. Therefore, it is the interplay of multiple molecular signals present in varying concentrations across different regions that drives the differentiation of functionally distinct areas within the developing neocortex. Importantly, when the concentration of a single protein is experimentally increased or decreased, the cortical maps are adjusted, reflecting changes in molecular signaling patterns [14].

Similar to genes, the environment enforces strict constraints on the developmental trajectory of an organism. From an evolutionary standpoint, development serves as an adaptation to environmental contingencies. Early development is dependent on what Greenough refers to as experience-expectant change. Normal development necessitates typical input from the environment to modulate and shape the evolving functional organization of neural systems. In the absence of standard environmental input, neural systems fail to develop properly [15]. The monocular deprivation studies mentioned earlier offer compelling evidence of the critical role that expected input plays in the development of these systems. The environment equally exerts a significant influence on the formation of neurobehavioral systems. For instance, research involving severely deprived human infants demonstrates the extensive impact of developmental conditions on various facets of neural, emotional, and cognitive well-being. Specifically, the overall brain size is reduced in children who have experienced severe deprivation.

More precisely, the amygdala and prefrontal cortex regions, along with their connecting pathways, exhibit abnormalities. This neural circuit is crucial for mediating emotions, and the identified neural irregularities likely contribute to the emotional regulation challenges frequently seen in these children. Comparable abnormalities are noted in neural systems responsible for language, visuospatial processing, and attention (refer to Bick and Nelson, Early experience and brain development, WIREs Cogn Sci, also included in the collection How We Develop).

A third crucial constraint stems from time. The integrity of the developmental process relies on the presence of the appropriate neural elements at the right moment. For instance, the differentiation of neural stem cells during early embryonic development lays the groundwork for the creation of the ventricular zone, a deep brain region housing neural progenitor cells. The establishment of the ventricular zone subsequently paves the way for the generation and scaffolding of neurons that will form the neocortex. Any failure at these critical stages can result in a disastrous outcome for brain development. This process is not solely governed by genes; rather, it unfolds over time [16]. Therefore, brain development is temporally constrained; the developing organism generates tools as needed for each subsequent developmental step. At any given moment, the organism possesses both a state and a history that restrict what can immediately influence it and its future development. For example, while light stimulation has minimal impact on fetal development, it becomes vital for the normal development of the visual system in newborns. Time constrains the changes that can take place and the factors that can affect development. In this regard, development is a self-organizing process.

The path of individual neurocognitive development unfolds over time through continuous interactions across various levels of the neurobehavioral system (see Brown, Individual differences in human brain development, WIREs Cogn Sci, also in the collection How We Develop). The processes of progressive differentiation and commitment consistently alter the organism's existing state, leading to multiple reorganizations throughout development [17-18]. Thus, development can be viewed as a process of ongoing, successive reorganization. The outcome of these developmental processes is a relatively stable (yet still plastic) organization within the adult brain.

Conclusion

Brain development is both dynamic and adaptive. It is defined by time and influenced by genetic and experiential factors. This dynamic approach contrasts sharply with older maturational models, where systems develop in a linear and predetermined manner. A growing body of research on brain development, along with studies that explore the connections between neural and behavioral growth, supports this model. Our scientific frameworks embody fundamental assumptions about the processes involved, thereby shaping the questions we pose, the experiments we design, the therapies we create, and the educational programs we implement. The dynamic model of brain development explains significant neurobehavioral impacts that deterministic models cannot adequately address. Recent research into neurodevelopmental disorders, early deprivation, and individual differences not only bolsters the dynamic model of neurobehavioral development but also reshapes our understanding of the brain.

References

1. Azevedo, F. A., Carvalho, L. R., Grinberg, L. T., Farfel, J. M., Ferretti, R. E., Leite, R. E., Jacob Filho, W., Lent, R., & Herculano-Houzel, S. (2009). Equal numbers of neuronal and nonneuronal cells make the human brain an isometrically scaled-up primate brain. *Journal of Comparative Neurology, 513*, 532–541.
2. Jablonka, E. (2002). Information: Its interpretation, its inheritance, and its sharing. *Philosophy of Science, 69*, 578–605.
3. Keller, E. F. (2000). *The century of the gene*. Cambridge, MA: Harvard University Press.
4. Keller, E. F. (2000). Decoding the genetic program: Or, some circular logic in the logic of circularity. In P. Beurton, R. Falk, & H.-J. Rheinberger (Eds.), *The concept of the gene in development and evolution: Historical and epistemological perspectives* (pp. 159–177). Cambridge: Cambridge University Press.
5. Sarkar, S. (2000). Information in genetics and developmental biology: Comments on Maynard Smith. *Philosophy of Science, 67*, 208–213.
6. Gottlieb, G. (1976). Conceptions of prenatal development: Behavioral embryology. *Psychological Review, 83*, 215–234.
7. Stiles, J. (2008). *The fundamentals of brain development: Integrating nature and nurture*. Cambridge, MA: Harvard University Press.
8. Berlucchi, G., & Buchtel, H. A. (2009). Neuronal plasticity: Historical roots and evolution of meaning. *Experimental Brain Research, 192*, 307–319.
9. Hübener, M., & Bonhoeffer, T. (2014). Neuronal plasticity: Beyond the critical period. *Cell, 159*, 727–737.
10. Kolb, B., & Gibb, R. (2015). Plasticity in the prefrontal cortex of adult rats. *Frontiers in Cellular Neuroscience, 9*, 15.
11. Kalia, M. (2008). Brain development: Anatomy, connectivity, adaptive plasticity, and toxicity. *Metabolism, 57*(Suppl 2), S2–S5.
12. Stiles, J., Brown, T. T., Haist, F., & Jernigan, T. L. (2015). Brain and cognitive development. In R. M. Lerner, L. S. Liben, & U. Mueller (Eds.), *Handbook of child psychology and developmental neuroscience* (pp. 9–62). New York: Wiley.
13. Pascual-Leone, A., Amedi, A., Fregni, F., & Merabet, L. B. (2005). The plastic human brain cortex. *Annual Review of Neuroscience, 28*, 377–401.
14. Tropea, D., Van Wart, A., & Sur, M. (2009). Molecular mechanisms of experience-dependent plasticity in visual cortex. *Philosophical Transactions of the Royal Society B: Biological Sciences, 364*, 341–355.
15. Black, J. E., & Greenough, W. T. (1986). Induction of pattern in neural structure by experience: Implications for cognitive development. In M. E. Lamb, A. L. Brown, & B. Rogoff (Eds.), *Advances in developmental psychology* (pp. 1–50). Hillsdale, NJ: Erlbaum.
16. Greenough, W. T. (1993). Experience and brain development: An update. In *Brain development and cognition: A reader*. Oxford: Blackwell.
17. Greenough, W. T., Black, J. E., & Wallace, C. S. (1987). Experience and brain development. *Child Development, 58*, 539–559.
18. Yaqob, K. The potential role of neuroplasticity in the core process of brain rewiring after brain insult.

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