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Fast and Efficient Connections in the Brain

Billions of neurons and connections in the developing brain drive how we think, feel, and act, enabling us to function and learn. These connections not only have to be fast but also efficient. An efficient brain uses its energy effectively to complete complex tasks via the relevant pathways, enabling the fastest flow of information throughout the entire brain. Fast and efficient brains learn better.[1,2]

Important Cellular Processes Underlying Brain Development[3]

The formation of new neurons in the brain is a process that is largely completed by birth, with the exception of very few brain regions that continue neurogenesis throughout adulthood. After birth, most brain processes are focused on building connections between these neurons to allow brain areas to communicate.

- **Axonal elongation and dendritic branching:** Neurons form specialized nerve fibers to allow information flow between neurons. Dendrites are shorter fibers that receive information and bring it to the cell body; axons are longer fibers that carry the information from the cell body to the synapse where the information will be passed to the next neuron.
- **Synaptogenesis:** The formation of synapses, which allow for the transmission of the information (electrical or chemical signals) from one neuron to another via neurotransmitters (signaling molecules) and receptors.
- **Synaptic pruning:** The process by which connections that are not used often after birth are eliminated, allowing for more efficiency, providing room for the most important networks of connections to expand, saving energy, filtering information, etc.[4]
- **Myelination:** The process of insulating axons to improve communication speed between neurons and to minimize signal loss, thus improving efficiency of the information flow.

Brain architecture is made up of billions of connections between neurons across the brain, forming highly complex brain circuits (networks), which are the foundation for us to live our daily lives, make coordinated movements, as well as perform complex tasks.[3] In the first few years of life, more than **1 million new connections form every second.**[5] Energy is required to maintain these highly complex brain circuits, and the more connections there are, the more energy that is needed. Additionally, long-range connections require more energy than short-range connections.[6]

A direct connection would be the fastest means to communicate between two brain regions. However, if all brain regions were directly connected, our brains would need to be extremely large and use tremendous energy to maintain all the neurons required. Instead, our brains form several regional "hubs" analogous to hub cities of different airlines. The hubs serve as regional information centers to directly communicate with distant hubs while gathering information from its neighbors. This makes our brains very efficient.[6]

Processes That Make Brain Connections Fast and Efficient

1. SYNAPTOGENESIS

Synaptogenesis occurs simultaneously with some other processes, such as dendritic and axonal growth.[7] Once a developing neuron reaches its final destination in the brain, it establishes contact with synapses of other neurons through the extension of axons and dendrites which stimulates the formation of synapses.[7] A fully developed neuron now consists of dendrites, a cell body, and an axon—and they can pass signals to other neurons via synaptic connections.

It has been suggested that early synaptogenesis is intrinsically regulated with no environmental control. Conversely, the formation of new synapses later in life has been shown to be influenced by environmental inputs, such as those occurring in response to learning, new experiences, and practice.

Synapses play an important role in connecting the brain. There is an overproduction of synapses early in life, with a number of synapses at levels nearly twice as high as those observed in the adult brain, followed by a slow decline to adult levels across the periods of childhood and adolescence.[8-12] The decline in these connections is a result of synaptic pruning, a process that occurs in different areas of the brain at different time points, the earliest in primary motor and sensory areas and later in the prefrontal cortex.[8,13]

2. SYNAPTIC PRUNING

Brain organization is activity-dependent,[14] which means that active synapses and connections are strengthened and less active synapses and connections are weakened or eliminated. After a period of rapid proliferation, excess connections are reduced through a pruning process that removes redundant connections, leading to increased efficiency and a reduction in required energy.[6] It is important to recognize that pruning is not temporally and spatially uniform; some brain regions undergo pruning earlier than others. For example, the primary visual cortex has been shown to undergo pruning within months after birth.

Pruning is considered an important step for brain development and organization. Environmental stimuli, such as learning and experience, are key to healthy pruning, shaping our brains to become efficient.

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3. MYELINATION

Several factors affect brain efficiency, including the distance of a connection, the number of connections, and more importantly, how effectively information can be transferred via axons. Specifically, one of the major aspects of brain maturation is the wrapping of axons with a lipid-rich sheath, a process called myelination. Axons act like telephone wires in that they are responsible for sending electrical signals (action potentials) to neurons in distant locations. The myelin sheath is responsible for insulation and making the transmission of electrical signals between different brain regions **fast** and **efficient**, i.e., increasing the speed at which the signal passes along the axon and minimizing energy-consuming signal loss.

Myelination is key to learning as it has been associated with processing speed and cognitive performance, such as language and reading skills,[15,16] and working memory.[17]

4. SYNAPTIC TRANSMISSION

Synaptic transmission is the biological process by which a neuron communicates with another cell across a synapse. These synaptic connections vary from simple, individual cell-to-cell contact to intercellular networks, and ultimately, more complex connections across the entire brain.[18] Synaptic transmission can be electrical or chemical. Chemical synaptic transmission involves the release of neurotransmitters from the presynaptic neuron. The neurotransmitters diffuse across the synaptic gap to the other neuron, where they bind to specific postsynaptic receptors.

Examples of neurotransmitters include glutamate (Glu), γ-aminobutyric acid (GABA), dopamine (DA), norepinephrine (NE), and serotonin (5-HT).

Factors That Make the Connections Fast and Efficient

The foundation of brain architecture is established early in life through a continuous series of dynamic interactions between genetic influences, environmental conditions, and experiences. Early experiences affect the development of brain architecture, which provides the foundation for all future learning, behavior, and health. Other important factors include socioeconomic status, physical activity, interactions with the parent/caregiver, and sleep.[19-21]

Good Nutrition is Vital for Brain Connections

Nutrition can provide structural and functional building blocks for the brain, provide energy, and impact neurochemistry, e.g., neurotransmitter and receptor synthesis. Certain nutrients have been documented to have an impact particularly during brain development—these include protein, iron, choline, zinc, copper, iodine, selenium, vitamin A, folate, lipids and fatty acids (long-chain polyunsaturated fatty acids [LCPUFAs]), and cholesterol.[22-25]

Phospholipids are critical components of the integrity, structure, and function of cells in the brain and the protective myelin sheath. One of the most abundant lipids in the brain is sphingomyelin (SM), which is also one of the most abundant phospholipids in human milk, making up 27% of the lipid content in human milk.[26] The effect of dietary SM has been demonstrated in both preclinical and clinical studies. Clinically, a pilot study in very low birth weight, preterm babies found SM-fortified formula was shown to be associated with improved behavior rating scores, information processing, and sustained attention at 18 months.[27] Recently, an observational study reported an association of SM as well as phosphatidylcholine (PC) in myelination.[28] The data suggest that dietary intake of these components may be important during the rapid brain development period.

Some proteins found in the manufacture of infant formula contain innate levels of lipids. For example, some sources of the protein alpha-lactalbumin contain complex lipids. In other words, the sources do not only contain protein but also five major phospholipids found in human milk, within the range found in human milk. Patented processes can result in up to three times more SM in the alpha-lactalbumin protein than the amount found in other protein sources.[29]

LCPUFAs have also been widely studied in brain development. Their impact on brain structure and function, in addition to visual development, is widely published where they help to regulate membrane function and intracellular communications.[22]

Active learning and/or continuous, positive, and age-appropriate stimulation will strengthen the connections in the brain to promote a child's cognitive abilities while removing redundant, unused connections—leading to a fast and efficient brain.

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