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Impacts of Prenatal and First-year Brain Development

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Abstract

This paper highlights a basic brain structure and typical sensorimotor development. This allows us to analyze the cognitive and sensorimotor effects of various deficiencies that occur prenatally or in the first year of life. Malnutrition impacts long term cognitive function, with varying possible degrees of remediation dependent on the degree of deficiency and the extent of damage. Frequently, the brain damage is too severe to be mitigated, but in some cases, measures can be taken to mitigate the severity of the impact.

Neurology is developing rapidly as a field due to recent advancements in imaging technology.[1] This rapid development has allowed neurologists to study for the first time not only how the brain functions, but specifically how children's developing brains function. Because of this, we can now search for specific vulnerabilities, allowing scientists the potential for intervention or remediation to prevent irreversible damage to growing minds. This rapid development has allowed neurologists to study for the first time not only how the brain functions, but specifically how children's developing brains function. Because of this, we can now search for specific vulnerabilities, allowing scientists the potential for intervention or remediation to prevent irreversible damage to growing minds.

Brain Structure

Even small human functions draw upon multiple regions of the brain. However, there are basic structural regions responsible for specific purposes. For example, the brain stem connects the spinal cord to the rest of the brain. It controls reflexive or involuntary practices, such as breathing—it's the part we get to thank for the fact that we don't have to consciously tell ourselves to take each breath. The cerebellum, at the base of the brain, is responsible for balance and coordination. The final and largest region of the brain, the cerebrum, enables higher thinking processes like learning and memory.

The cerebrum is covered by the cerebral cortex. The cortex is less than ¼ inch thick, but it has folds that allow it to maximize surface space. This gives the brain ridges (gyri) and grooves (sulci). The cortex is divided into four lobes per hemisphere: the occipital lobes in the back, the temporal lobes on the sides, the parietal lobes on top, and the frontal lobes in front.[2] The occipital lobes control sight; the parietal lobes control sensations caused by external stimuli; the temporal lobes control language skills, among other skills; and the frontal lobe is involved with planning, impulse control, and other related skills. The pre-frontal cortex is the last area of the brain to mature prenatally and continues developing

[1] D. Meyers, *Psychology* (New York City: Worth Publishers, 2009).
[2] *Ibid.*

in adolescence. This makes it extremely susceptible to damages that permanently affect an individual's life.

On the cellular level, the brain is composed of neurons.[3] These form networks of cells that send electrical and chemical signals which constitute the basics of learning and memory. A neuron is a cell body with branches, known as dendrites, and a long axon covered by a fatty substance, or a myelin sheath. In between neurons are synapses, or gaps through which electrical signals jump. Babies are born with all of their neurons, but their synapses form over the first two years of their lives. After two years, a process called blooming and pruning allows the brain to kill off useless synapses to hone skills and develop specialized abilities. The skills that are kept into adulthood are the ones following strong neural paths: they consist of the things we did most often as children. Thus, parents have the ultimate impact on what their children's abilities later in life will be.

Brain Development

The first formation of the brain occurs prenatally throughout all three trimesters. In the first trimester, the brain gains its basic structure without detailed specialization, like the outline of a project waiting to be completed. The neural tube is the first structure to form: embryonic cells forming the neural plate coalesce into a tube that eventually shapes over time into the brain and spinal cord.[4] After that process, the neurons and synapses develop, allowing the first movements of the growing fetus. During the second trimester, the gyri and sulci form across the surface of the brain as the cerebral cortex develops and synapses form. Myelination begins to occur in these months, with myelin (a fatty substance) covering the axons of neurons to facilitate the speed information traveling across synapses. Without these myelin sheaths, the spinal cord would need to be three yards in diameter.[5] In the final trimester of the pregnancy, the cerebral cortex officially switches on, taking over processes such as responding to external stimuli.

Babies are born with an outstanding degree of ability belied by their limited capacity to interact actively with the world. They can recognize faces and simple expressions, as well as recognize familiar voices, particularly their mother's. The development from this point into the next few years is the most rapid period of brain development to ever occur in any individual's life. The cerebellum triples in size, leading to increased motor skills. Synapses continue to connect in the occipital lobes, improving an infant's sight from dim outlines to full binocular vision.[6] Growth of the hippocampus increases memory capacity. Finally, the synapses in the language cortex of the brain begin to become specialized. It is for this reason that a newborn can be raised to learn any language, but after the first year or so begins to distinguish their natural dialect as is spoken at home.

Nutritional Effects on Development

Nutrition is inarguably important in maintaining a healthy human body. As Prado and Dewey claim, "Nutrition is especially important during pregnancy and infancy, which are crucial periods for the formation of the brain, laying the foundation for the development of cognitive, motor, and socio-emotional skills."

[3] *Ibid.*
[4] T. McDevitt and J. Ormrod, Child development and education (Upper Saddle River: Pearson, 2013)..
[5] *Ibid.*
[6] *Ibid.*
[7] E. L. Prado and K. G. Dewey. "Nutrition and Brain Development in Early Life." Nutrition Reviews 72, no. 4 (2014): 267.

For the neural plate to even form, the embryo needs folic acid, copper, and Vitamin A. Yet, despite the scientific community's knowledge of some specific impacts of early nutrient deprivation, such as the former example, many impacts remain unknown and can be influenced by multiple factors. The degree of nutritional deprivation, the timing of deprivation, and the child's external environment all have an impact on the extent of cognitive and physical impact as well as the degree of possible recovery.

Certain nutrients are more important to specialized development at particular times. When deficiency occurs during those periods, the severity of detrimental impact increases. One such important process is the myelination that occurs during the second trimester.[8] Docosahexaeonic acid (DHA) is necessary for the synthesis of myelin. Scientists believe that adding dietary supplements of DHA during the third trimester and into the first year of life can improve the process of myelination, particularly regarding auditory pathways. When tested, this hypothesis showed merit: infants fed formula with DHA showed more activity in the auditory sections of their brains than infants with regular formula. This clearly demonstrates that the timing of nutrient deprivation impacts the degree of later disability.

The degree of nutrient deficiency also has an impact on the severity of deleterious developmental effects. More severe deprivation leads to more damage than moderate deficiency. Homeostasis ensures regulated development regardless of external insufficiencies; while this process can only offset inhibited development in moderate cases, the re-prioritizing of necessary processes and growth during development can prevent severe damage from occurring. In places of placental insufficiency, the fetus will have decreased blood flow to peripheral tissue, as the brain and heart are the most important organs to sustain.[9] Not every nutrient deficiency can be offset by homeostasis, and each is offset to varying degrees. While proper nutrition is preferable, the body does have ways to remediate mild insufficiencies.

In more severe cases of nutritional deprivation, more negative side effects are likely to occur. However, the chance that a child can later be helped with nutrient supplements also increases proportional to the severity of the initial deficiency. Iron deficiencies can result in stunted cognitive and motor development. Cognitive impairment often remains despite iron supplementation; however, supplements often consistently decrease the impairments long-term. In five trials, motor development skills increased with iron supplementation; in two trials, language development and vocabulary scored higher; and in three trials, the children were more socially adept within their community.[10] Iodine is an even more essential nutrient, because it impacts neurogenesis. One severe impact of reduced or absent iodine nutrients is cretinism, characterized by mental retardation, facial deformities, deaf-mutism, and severely stunted growth.[11] This particular disorder cannot be mitigated with any supplements. However, when cretinism is not present, iodine deprived children often present lower IQ scores than children without a history of iodine deficiency. Scientists are still unsure whether supplementation can have any positive effects on reducing the cognitive impairment caused by this deficiency in the absence of cretinism. So, severe cases of nutrient deficiency are a

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[8]J. K. Moore, L. M. Perazzo, and A. Braun. "Time course of Axonal Myelination in The Human Brainstem Auditory Pathway," (2009).
[9]Prado and Dewey. "Nutrition and Brain Development,"
[10] S. P. Walker, T. D. Wachs, and J. M. Meeks-Gardner. "Childhood Development: Risk Factors for Adverse Outcomes in Developing Countries," *Lancet* 369.
[11]Prado and Dewey. "Nutrition and Brain Development"

toss-up in a biological game of chance: some can show great improvement with supplementation, while others are unsalvageable.

The final effect on the impact of undernutrition is the child's environment. Experience controls brain development in two ways: experience-expectant processes and experience-dependent processes. An experience-expectant process develops the brain based on input received from the external environment. This, for example, is why children pick up their native language: the auditory stimuli from the environment shapes the brain's formation in a way that supports linguistic learning based on the family's spoken dialogue. Experience-dependent processes shape the brain to allow for the development of new skills, the same way as frequently used muscles strengthen to support repeated tasks. The first type of development has a holistic impact on the brain's structure, while the second is more specialized and unique. Both are extremely valuable to cognitive development, and in the absence of these, cognitive growth will be stunted, with or without malnutrition.

Proper cognitive stimulation has the power to offset the impact of malnutrition in children. Studies have shown that undernourished children who are not externally stimulated fall behind the average in preformed tasks. Depending on the type of nutritional deficiency, well-stimulated children can perform equally as well or better than well-nourished, under-stimulated children of the same age. In Vietnam, children with nutrient deficiencies who participated in preschool programs between the ages of three to four showed higher cognitive scores between the ages of six to eight than children of similar levels of nutrient deficiency who did not attend preschool classes.[13] While the ideal situation for cognitive development is a well-nourished, highly stimulated environment, providing one of the two is always better than the complete absence of both.

Sensorimotor Development

Motor and sensory development tends to occur in phases marked by milestones. Children reach milestones at approximate ages, but no specific date is set for when each child should possess each ability. The age a child begins to walk varies, but all children with typical development eventually learn around the one year mark. Newborn babies have very little control over their bodies; the first year of life is a period of rapid growth and discovery unparalleled in the child's life.

In the first three to four months, babies learn the basic building blocks for sensorimotor development. They develop control of their heads, they can grab for toys, and they can sit

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[12] *Ibid*.
[13] K. Watanabe, R. Flores, and J. Fujiwara. "Early Childhood Development Interventions and Cognitive Development of Young Children in Rural Vietnam," *Junior Nutrition* 135 (2007).
[14] Gurian, Anita. "Motor Development: The First Five Years," *The Child Study Center* (NYU: Langone Medical Center).

without falling when supported by a person or object. They can see objects a foot away, follow objects with their eyes, and begin to coordinate their vision with their bodies. This is due to proprioception. Proprioception is a sense, like hearing or sight, that gives the child a sense of its body in space.[15] This allows a baby to ascertain the control it will eventually be able to exert upon the physical world.

Between five and eight months, babies begin to develop more specialized skills. Babies can roll from their backs on to their stomachs and support themselves when sitting up. They can focus both eyes equally to utilize binocular vision. They begin to crawl during this period and refine finger usage, rather than continuing to use less nimble fists and palms for grabbing motions. Most importantly, during this time they begin to mimic the steps of walking, although they still need to be supported and guided by adults.

Between nine and twelve months, babies gain a new degree of mobility and self-sufficiency. While far from adulthood and the ability to fend for themselves, they can now grab their own toys without falling over. They can push themselves from a prone to a sitting position without assistance. They recognize people and begin to pair words with objects, the beginnings of a vocabulary developing in their minds. They develop more complex emotions such as anger and fear of strangers. Binocular vision is now a completely specialized process. At twelve months, babies can say simple words. They can now stand on their own and take independent steps, although they still frequently fall and do not yet possess complete sensorimotor control.

One specific skill that develops during the first year is object control. This is a honed motor skill that allows individuals to categorize similar items and adjust their interaction with the objects accordingly.[16] Researchers Clay Marsh and Marc Bornstein (2014) devised an experiment to test object control in infants. Every individual action, such as lifting a glass to drink, requires the specific coordination and choice of movement potentials. In this experiment, babies of varying ages were given objects to lift and play with. Control objects weighed similar amounts, and test objects weighed less. When infants put too much force behind their lifts, it indicated that they remembered the similar control object weighing more and adjusted the force of their lift accordingly. This memory-to-action skill developed around nine months in the infants who participated in the experiment. This sensorimotor adaptation to interaction with the child's environment displays the effects of the strengthening neural pathways within the motor cortex. As these synapses generate and strengthen with practice, the child's ability to use specialized motor control advances.

Infant motor development is also connected to the characteristics of each child.[17] Perception, motivation, and movement are linked in early childhood advancements.[18] This is why playtime is so important to young children; fun encourages them to explore their environment, providing the motivation to learn and hone motor skills. Motivation forges the link between an individual's temperament and their physical growth. Dorlap and Barlett conducted an experiment in 2014 to study these temperamental impacts on child development in the first year.[19] Children

[15]Gurian. "Motor Development."
[16]G. Marsh, M. H. Bornstein, and A. Banerjee. "Development of Object Control in the First Year: Emerging Category Discrimination and Generalization in Infants' Adaptive Selection of Action." *Developmental Psychology* 50, no. 2 (2014).
[17]S. Dorlap and D. Barlett. "Infant Movement Motivation Questionnaire: Development of a Measure Evaluating Infant Characteristics Relating to Motor Development in the First Year of Life," *Infant Behavior and Development* 37, no. 3 (2014).
[18]Von Hofsten, "An action perspective on motor development," *Trends in Cognitive Science*s 8.
[19]Dorlap and Bartlett. "Infant Movement Motivation Questionnaire,"

who were noted to be more active also tended to show signs of advanced motor development, which could be explained by the strengthening of synapses in the motor cortex due to the child's increased action. Children's curiosity was another temperament that remained constant over time and improved motor coordination and advancement. Curiosity led to increased opportunity for exploration that allowed children to be flexible in their responses to the various situations in which they found themselves, such as the best way to pick up a toy or how to move their arms as they learned to crawl. Motivation, categorized by an infant's perceived enjoyment, anticipation, and awareness, was linked to increased movement. Dorlap and Barlett supposed that this could be attributed to increased awareness in these infants, who then were more aware of their success, became excited by the positive outcomes, and were encouraged to continue favorable actions. Finally, adaptability, while not reliably an inherent trait, did show a positive correlation with superior motor advancement. Adaptable children were more stubborn in their attempts, refusing to give up an action until they had succeeded. Thus, an infant's temperament, innately wired into their DNA, affects the advancement of a child's motor development.

Impact of Atypical Development

While an understanding of how infants should interact with their surroundings in their first year of life is undoubtedly important, the fact that every action draws upon numerous parts of the brain makes studying the effects of neural development on motor ability difficult. Studying cases of brain injury and its subsequent impact on child development can aid in scientists' understanding of what specific areas of the brain influence individual actions.

Dusing, Izzo, Thacker, and Galloway conducted a longitudinal study of three infants during their first years of life to measure the impact of white matter injury on cognitive and motor function.[20] They proposed to study this impact by measuring the postural complexity of the infants: the infant's control of their own body and ability to manipulate it to suit their intended goals. These studies centered around the perception-action theory, in which cognitive function (an infant's perception of the environment) and motor skill (ability to react to the environment) are both dependent on and enhance one another.

Why is postural complexity so important to this? The ability to sit up without falling over, to reach for an item without missing it, to hold an item without dropping it: these are all part of postural complexity. A lack of postural complexity, or ability to act, causes delays in perceptive learning that, in turn, lead to longer developmental delays. Excessive complexity, likewise, damages infant's function because they cannot adapt their movements to different external demands; low complexity provides no stability in strategies toward interacting with the environment, so any successes infants have in any task are lost. The optimal amount of postural complexity, which naturally diminishes over the course of the first year as infants hone their motor function, is the ability to try different tactics in new tasks until they discover the most efficient strategy.

Three infants born between twenty-four and twenty-eight weeks (excessively premature) were studied. All three had periventricular leukomalacia, which causes holes in the brain. The infants were assessed with the Test of Infant Motor Performance (TIMP),

[20] S. C. Dusing, T. Izzo, L. R. Thacker, and J. Cole Galloway, "Postural Complexity Influences Development in Infants Born Preterm With Brain Injury: Relating Perception-Action Theory to 3 Cases," *Physical Therapy* 94, no. 10 (2014).

useful up to four months of age, and the Baley Scales of Infant and Toddler Development, used from four to twelve months.[21]

The first infant showed linguistic and cognitive strength but exceptional motor delay. She could not reach for a toy until she was six months (age adapted) old. Her postural complexity declined rapidly in the first three months but then rose back to average levels around six months; the scientists posited that this was because she focused her cognitive resources visually on the toy until she could reliably focus her eyes enough to redirect her focus toward motor control. Her adaptive strength proved the connection between motor and cognitive function.

The second infant showed close to average motor skill but severe cognitive deficits. The infant displayed low postural complexity early in life, which damaged the degree to which his perception benefited from his action. Thus, while he quickly developed motor skills later on, including the ability to pull himself up to standing by twelve months, his cognitive development was negatively impacted.

The final infant had average postural complexity in his first four months. At five months, he developed delays, most significantly to his motor development. He could focus on toys by two months, but could not reach for them until he reached six months old. Over time, his postural complexity increased, leading to reduced efficiency of his movements that led to developmental delays.[22] Despite this, he could stand independently at twelve months and walk shortly after. His average postural complexity in the first four months of life mitigated the motor damage caused by his brain injury, although his cognitive function was permanently impaired.

Little could be discovered by way of how specific brain injury would impact these infants. All three children did, however, show significant motor and/or cognitive delays resulting from the brain injury. The difference in display highlights the utter complexity of brain structure and function and the growth still to come in the neurological field.

Conclusion

The field of neurology has allowed scientists to gain a great degree of knowledge of brain structure and function. This understanding is only beginning to be applied to studies of normative sensorimotor and cognitive development in both children and adults. The effects of brain damage are difficult to study both because so many areas of the brain are necessary to each individual function as well as because similar damage impacts individuals in different ways. Still, experiments with nutritional supplements and cognitive stimulation show hope for at least some children with damage due to deficiencies. Continual study will hopefully discover more about remediating damage in small children so they can live healthier adult lives.

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[21]Dusing, Izzo, Thacker, Galloway, "Postural Complexity,"
[22]*Ibid.*

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