

Developing Brains- Ideas for Parenting and Education From the New Brain Science

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Brain Development

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Brain development and its implications have been a topic of much interest since the mid-1980s in the United States. The following is a brief overview of brain development and some of the implications for parents, teachers, parenting educators, and others interested in the development of children.



Five Stages of Brain Development: an overview

Brain development during prenatal life is indeed amazing! The brain develops in five stages, and the first four of them occur before the baby is born. The fifth stage, however, is the longest, as it continues throughout the lifespan.

The Five Main Stages of Brain Development include (Gilkerson and Klein 2008, 4-9):

- Neural tube formation - the basis of the brain and spinal cord
- Cell proliferation - the creation of new cells from existing cells¹
- Cell migration - cells move to the location where they are supposed to be
- Cell differentiation - after migration they "take on their own unique shapes and functions" (4-17)
- The formation of cell connections - axons and dendrites connect with other neurons

¹ Early in development, "more than 250,000 cells are produced every minute!" (Gilkerson and Klein, 2008, 4-12)

How the brain gets started: temporary neural structures are created and then disappear during earliest period.

By the 3rd week after conception, a **neural tube** begins to form. Cells produced in the neural tube must replicate (duplicate) themselves and then **migrate** (literally “move”) to their location in the brain and lay down connections linking the different parts of the brain. The neural tube eventually transforms into the brain and spinal cord.

Prenatal Folic Acid Deficiency is linked to neural tube defects, such as: spina bifida (open spine) or anencephaly (incompletely formed brain).

The progression of neurological development

“Every cell in the nervous system has its own developmental history, which can be traced through successive cell divisions from the fertilized egg.” (Kandel 1995, 91) **Neurons** and **glial cells** are the two major classes of cells in the nervous system. “The typical neuron forms about 1,000 **synapses** and receives even more.” (Kandel 1995, 709)

During first 4 months of gestation, neurons in the brain are involved in:

- a. **Neurogenesis**, which refers to the formation of new neurons from undifferentiated stem cells. (Wolfe 2001, 16) Then these cells duplicate themselves at a very rapid rate.
- b. **Migration** to a specific location which occurs along **glial² cells** (like “highways”) for neurons in the cerebral cortex. If damage occurs during migration, neurons can adapt and “invade” a new part of the brain where the damage is.
- c. **Aggregation**, which is when a cell is teaming up with other “like” cells according to molecular markers on the surface of the cells.

² Specifically, “radial” glial cells. “Glial cells are between 10 and 50 times more numerous than neurons and are the “scavengers of cellular debris following injury or neuronal death.” (Kandel, 1995, 706)

The characteristics that assist neurons in this teaming up include:

- location
- type of electricity generated
- shape of the cell
- texture
- chemicals

- d. **Gender** differentiation of some brain structures begins at about 9 weeks and is impacted by the presence or absence of testosterone and other hormones. Though all human brains are both similar and unique, some differences that are seen are based on the sex of the child.
- e. Around 7 months gestation, convolutions begin to appear in the cortex, which indicates the rapid growth of this area. (Wolfe 2001, 17)
- f. During the 3rd trimester, the fetus can respond to sound and detectable light levels, thus learning begins to occur! (Wolfe 2001, 17)

The brain grows from simple to complex and from inside to outside.

"The nervous system has a greater variety of cell types than any other organ of the body." (Kandel, 1995, 90)

The first part of the brain to develop is the **brain stem** (regulating heart rate, body temperature, blood pressure). Second is the **mid-brain** (controlling sleep, appetite, and arousal). Then comes the **limbic area** (center of emotional activity).

Finally the **cortex** develops (where rational and analytical processes occur). "The layers of cortical neurons appears to be associated with the *birthdays* of these neurons" with early neurons composing the inside layers and later neurons composing the outer layers. (Kandel, 1995, 99)

At birth the brain has about 100 billion **neurons** and a trillion **glial cells**, but the trillions of connections between the cells (**synapses**) made shortly after birth have yet to stabilize. (Berger 2001, 136)

Overall, the number of synapses per neuron reach their highest densities at about age 2 (Berger 2001, 136) and remain at that level until age 10-11 when a massive **pruning**³ occurs. From 4-10 years of age, the brain cells are intensely

³ Pruning is also called "programmed neuronal death."

"learning" which connections to keep and which to discard based on experience. "Neurons that fire together simultaneously are more likely to fire together again in the future." (Wolfe 2001, 76)

You either use it, or lose it, as brain growth is "use-dependent" according to Dr. Bruce Perry. Another way to look at this is described in a quote by Siegel as cited in Wolfe (2001, 76): "Neurons that fire together, survive together and wire together."

"An interpretation proposed by Greenough and his colleagues suggests that the purpose of synaptic overproduction is to capture and incorporate experience into the developing synaptic architecture of the brain..."(Thompson and Nelson, 2001, 9)

It is the overproduction of **synaptic connections** (called synaptogenesis or transient exuberance⁴) followed by their loss (synaptic retraction or reduction) that leads to efficiency in brain functioning. (Thompson and Nelson, 2001)

Thompson and Nelson point out that the timing of synaptic overproduction and pruning differs for each part of the brain, for example:

Area of the brain	Peak of overproduction	Gradual retraction until adult density is reached
Visual cortex	4 months postnatal	Middle/end of preschool period
Medial prefrontal cortex ⁵	1 year of age	Middle/late adolescence

The higher numbers of connections (**synapses**) make for greater flexibility in learning (**plasticity**), but after adolescent pruning (by age 18-25) there is increased power at the expense of plasticity.

At Birth - approximately 50 trillion synapses

At 1 Year - about 1000 trillion synapses

At 20 Years - about 500 trillion synapses

4 Transient exuberance is defined as the great increase in the number of neurons, dendrites, and synapses that occur in the brain during the first two years of life.

5 The medial prefrontal cortex is "the area of the brain where some forms of higher level cognition and self-regulation take place"

Between ages 2 and 16 years, the brain loses $\frac{1}{2}$ of all neurons in the process of "sculpting" circuits in the brain based on experiences. As one neuron connects to another neuron, via the axon, *if it connects*, a chemical feedback from the target neuron turns off a "suicide" switch and the neuron stays; *if it does not connect*, the neuron gets no feedback and dies.

After age 16 and through adulthood, some things stabilize in the brain, and some things change or begin to change. For example:

- reaction times begin to slow
- learning time slows
- vocabulary improves
- new neurons can be produced in some areas of the brain, but not in the numbers we saw in infancy

Throughout life, the brain retains "considerable functional plasticity." (Thompson and Nelson, 2001, 10) Environmental stimulation increases the number of synapses or connections between neurons, and there is "cortical reorganization based on adult experience." (Thompson and Nelson, 2001, 10)

The brain goes through stages or levels of development (13 according to some researchers) where there is first a rapid expansion of connections between neurons (proliferation of synaptic development) followed by a pruning of some of these connections which reduces plasticity, in exchange for gains in power as the remaining connections are integrated into existing systems, reorganizing the brain. The stages build on the ones that come before it and it is postulated that over half of these stages occur in the first 2 years of life.

Children born into "high risk" situations need intervention in the first 24 months of life to prevent serious developmental delays. Interventions that begin at birth through the preschool years show significant effects that persist into adolescence. Interventions that occur after age 5 show little effect (Karr-Morse and Wiley, 1997).

As learning occurs, there is a synaptic reorganization of the brain. All forms of learning and experience are more highly influential during greatest plasticity (birth to young adulthood), with life-long effects. The first 6 years of intense plasticity are prior to formal education for many.

The ability to learn a second language, for example, is highest between birth and 6 years. Early music instruction (beginning in the preschool years) helps the child learn music better and play the instrument with greater facility, as more of the neurons that control the parts of the body in playing the instrument are retained.

Nutrition is essential for brain development and functioning

"Nutritional adequacy is a crucial prenatal and postnatal influence on brain development," for example, folic acid, iron, vitamins, fat, etc. Malnutrition is referred to by Thompson and Nelson (2001) as a "biological hazard to which the developing brain is especially vulnerable." (11)

Protein deficiency can lead to a deficiency in the production of two neurotransmitters: serotonin (which allows information to be transferred from one cell to another) and dopamine (which modulates impulsive behavior).

The brain begins working before it is finished developing

The brain is the only vital organ of the body that is not fully developed at birth, and it is dependent upon experience obtained through the senses to complete its development.

The basic or "foundation" pattern of connections (synapses) laid out *prenatally* by genetics is the "best guess" about what is required for hearing, vision, language, reasoning, etc. in each of the specialized areas of the brain. Then, neural activity stimulated by input from experience through the sensory organs, refines this "blueprint". Through the process of pruning, synapses that are stimulated repeatedly by experience and sensory input are strengthened. Those seldom or never used will atrophy (die), leaving a unique brain and mind.

Input during early development is critical. For example, children who don't play much or are rarely touched, have brains that are 20-30% smaller than typical for their age.

Rats raised in stimulating surroundings compared to rats raised without stimulation had brains that contained up to 25% more synapses per neuron.

During the first year or so, glial cells cover neurons with **myelin** (fatty covering) which provides both insulation (to speed transmission and increase complexity of neural impulses) and substance (bulk) to the brain. (Berger 2001, 137) Newborns' brains do not have much myelin and their brains are "mushy" and vulnerable to physical trauma.

Newborns heads must be supported (due to weak neck muscles) to prevent an injury to the head, resulting in brain injury.

Shaken Baby Syndrome can lead to loss of sight or hearing, mental retardation, and even death.

Some parts of the brain require appropriate stimulation at a particular time.

There are **critical periods** during which there is a relatively narrow "window of opportunity" open for a certain structure (and function) of the brain to develop. If the appropriate stimulation does not occur, that structure will fail to develop properly or not at all. "In humans, there are relatively few critical periods for brain development." (Thompson and Nelson, 2001, 9) An example of one that is known about is that for vision (see below). If the brain does not get input from each eye, the cortical space not stimulated will be "taken over" by the "good" eye.

A **sensitive period** is a less precise period when key functions are heavily influenced, but abilities are not impossible to acquire after this period. During a sensitive period, learning in that area can be influenced to a high degree by the environment and relationships with other people. For example, developmental scientists know that exposure to normal speech in the first year confers on the infant the ability to discriminate speech sounds and eventually to correctly produce those sounds." (Thompson and Nelson, 2001, 9) Some researchers speculate that during these sensitive periods, several systems of the brain are integrating, rather than one system developing.

The first 33 months of development (9 months prenatal and the first two years after birth) are a sensitive period for development of most basic structures of the brain, including those whose functions include emotional perception and control. However, brain development is life-long. For example, "the brain regions most relevant to higher cognition, including reasoning and problem solving, self-regulation, personality, and strategic functioning have a maturational course extending into adolescence...." (Thompson and Nelson, 2001, 9)

Vision: Between 2-8 months of age, there is a growth spurt in the vision part of the brain. If not stimulated early on, the visual system will not develop and the eye loses its functional connection to the brain. The baby will be blind. This is an example of a "critical" period.

It is important that vision problems be corrected as early in infancy as possible (congenital cataracts, muscular problems, etc.).

Hearing: during first 12 months of life, the part of the baby's brain that recognizes and learns to carefully hear (discriminate) sounds in the environment begins to focus on (structure a map of) the sounds of the language spoken to the baby.

A baby, who is raised in a bilingual environment, where both languages are spoken to the child, will have an easier time hearing the sounds of both languages and will be better able to pronounce the sounds without an accent.

Babies are able to learn any language sounds, but after 11-12 months, they lose their "universal" ability to discriminate ANY sounds in favor of focusing on the ones they have heard. By one year of age, babies are babbling in their native language.

Ear infections in the first year of life may interfere with hearing different sounds and could influence speech and language development.

Touch: Touch is essential to growth and survival. In a study on the importance of touch at the University of Miami, premature babies in a hospital were

assigned to two groups. One group received typical intensive care. The other group received similar care, but in addition got a 15 minute massage three times a day.

Babies who got the massage:

1. Gained weight 47 times faster than the babies who did not get massaged
-due to processing food better, not eating more
2. Were more alert and aware of their surroundings
3. Slept deeper and the sleep was more restorative
4. Cried less
5. Showed greater improvement in three measures of **temperament**:
emotionality- toward being more positive;
sociability- toward being more open to new experiences; and
soothability- toward less crying

Toddlers have better language development if, at an earlier period, they could pay attention for a long time, smiled and laughed a lot, and were easily soothed. The ability of the child to pay attention (especially when a parent is teaching the child something) helps in learning the names of objects or labeling.

Expression of ones feelings and emotions compete with speech (language expression) for resources or energy in the young child. Crying interferes with language learning as does having frustrating experiences with objects. The ability to be soothed quickly when upset gives the child more energy for language development. In fact, the act of soothing often entails the parent redirecting the child's attention to objects or events.

Patting a child or moving in rhythm while holding them is correlated with improved language comprehension, enunciation, speech flow, attending and in-tune singing (Weikart 1998).

Parents and caregivers who cuddle, hold, talk to, and sooth their infants will have toddlers who will be easier to take care of and who will develop better in all ways, including language.

Experience determines the structure of the brain and can impact later thoughts, feelings, growth, and behaviors throughout the whole life.

Emotions are critical in all learning. The author, Robert Sylwester, (as cited in Wolfe 2001, 86) states, "Emotion drives attention, and attention drives learning." The brain is programmed by biology "to attend first to information that has strong emotional content." (Wolfe 2001, 88)

New research is "showing that the nature of caregiving...shapes patterns of reactivity to stress." (Gilkerson 1998). This research by Gunner, et. al., found that when faced with a fearful situation (such as, getting a shot) securely attached, but fearful, infants showed *less stress hormone* release than insecurely attached, fearful children.

Lally (1998) states that "it has been shown that lack of early nurturance and prolonged stress can set emotional thermostats affecting brain functioning..., sometimes even increasing the secretion of cortisol [a stress hormone], lowering levels of serotonin and elevating levels of noradrenaline [both neurotransmitters]. It has been hypothesized that lack of nurturance in infancy can lead to depression, loss of impulse control, and heightened aggression in later life" (46)

Abuse and neglect can *over-activate* the emotional arousal part of the brain, leaving the child with a hyper-startle response. The brain gets structured or "built" in a pattern of protective behaviors (such as disassociation and a preference for rote learning) which interfere with later development, social behavior, and problem solving.

Caldwell (1998) reports on Gunnar's research of 1996 which "has shown that stressful experiences in childhood are associated with high levels of cortisol (measured by taking saliva samples). High cortisol levels are associated with a reduction in the number of available synapses in part of the brain and, in turn, with both cognitive and social developmental problems."

Increased cortisol levels interfere with learning, heart rate, and overall growth (Ten things every child needs 1997). Under conditions of stress, "emotion is dominant over cognition; and the rational/thinking cortex is less efficient." (Wolfe 2001, 111)

In research using the EEG (which measures brain wave activity in different areas of the brain), it was found that "children of depressed mothers show decreased cortical activity that essentially parallels what is seen in their mothers" (Caldwell 1998).

A secure attachment to one or more adults is one of the key factors in child resilience (Caldwell 1998) as are intelligence, a sense of trust, ability to have empathy, ability for effortful or self-control and a positive affect or mood in the child (Karr-Morse and Wiley 1997). Supportive parenting and caregiving, (a style that is full of explanations for behavior and parental demands and which focuses on the individual child's learning rather than on control), will structure the child's brain in a way so that these positive social behaviors predominate in them.

Some last cautionary notes

"Most scientists believe that deprivation [in the early years] must be quite severe to stunt normal brain development." (Berger 2001, 138) We must resist interpreting this data on brain development in a "doomsday" manner.

Thompson and Nelson (2001) caution that, "influences during the early years of life are important, but parents, practitioners, and policymakers are mistaken if they conclude that establishing a foundation of optimal brain stimulation early in life will **alone** ensure satisfactory development in the years to come.... They are also misled if they do not understand how much brain growth during the prenatal period provides a foundation for what follows after birth; thus, many important constituents of brain functioning are established before birth rather than afterward. Finally, the focus on early childhood suggests that later achievements in brain growth are primarily the outcome of early formative influences, but the new discoveries of continuing brain plasticity suggest that unique influences on neurobiological development occur after early childhood." (10-11)

In conclusion

Galinsky (1997) states that children need warm and responsive care for healthy development. "Warm means being loving. It means holding, touching, hugging,

and comforting. It means expressing joy in who the child is and helping her feel safe and secure. Responsive care is a complex concept. It means responding to the child's cues and clues."

Galinsky goes on to say that "it is important to state that being responsive is not *flash cards*. It is not one-way stimulation from the adult to child. It is not pouring in information. Being responsive is becoming involved in the so-called dance with the young child and engaging the child to be a learner." (10)

Sources:

Berger. The Developing Person Through the Life Span. 5th Ed. New York: Worth Publishers, 2001.

Caldwell. "Early Experiences Shape Social Development." Child Care Information Exchange. (121), May/June 1998, 53-59.

Dixon and Shore. "Temperamental Predictors of Linguistic Style During Multiword Acquisition." Infant Behavior and Development 20 (1), 1997, 99-103.

Florida *Starting Points Initiative*. Maximizing Washington's Brain Power. Washington State Child Care Coordinating Committee (1997).

Galinsky. "New Research on the Brain Development of Young Children." NCJW Journal. Fall 1997, 8-10, 27.

Gilkerson. "Brain Care: Supporting Healthy Emotional Development." Child Care Information Exchange. (121), May/June 1998, 66-68.

Gilkeerson and Klein, Eds. Early Development and the Brain: Teaching Resources for Educators. Washington, D.C.: Zero to Three, 2008.

Goldsmith, Buss, and Lemery. "Toddler and Childhood Temperament: Expanded Content, Stronger Genetic Evidence, New Evidence for the Importance of Environment." Developmental Psychology 33 (6), 1997, 891-905.

Kandel, Schwartz, and Jessell. Essentials of Neural Science and Behavior, (1995).

Karr-Morse and Wiley. Ghosts from the Nursery: Tracing the Roots of Violence. New York: Atlantic Monthly Press, 1997.

Lally. "Brain Research, Infant Learning, and Child Care Curriculum." Child Care Information Exchange. (121), May/June 1998, 46-48).

Ten Things Every Child Needs. (Video) Chicago: Robert R. McCormick Tribune Foundation, 1997.

Thompson and Nelson. "Developmental Science and the Media." American Psychologist. Vol. 56, No. 1. January 2001, 5-15.

Weikart. "Facing the Challenge of Motor Development." Child Care Information Exchange. (121), May/June 1998, 60-62.

Wolfe. Brain Matters: Translating Research into Classroom Practice. Alexandria, VA: Association for Supervision and Curriculum Development, 2001.

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