

Early Brain Development: Implications for Early Childhood Programs

Introduction

In July 1990, the first President Bush proclaimed the years from 1990 to 2000 to be the “Decade of the Brain.” During that time period, the National Institute of Mental Health of the National Institutes of Health sponsored a unique interagency initiative to enhance public awareness of the benefits to be derived from brain research. Earlier findings from the field of neuroscience began to be integrated with and applied to other disciplines, including child development, psychology, and education. The resulting synergy has produced tantalizing research and speculation about the possible ways nature and nurture stimulate and regulate one another. In addition, new brain imaging techniques produced visual images that intrigued and attracted the attention of many, including the media.

The development of the brain is a complicated matter. Some neuroscientists have called this organ the most complex structure in the universe. So it is not surprising that the spotlight of excited public attention has sometimes led to oversimplification and misunderstanding, as well as faulty generalizations and applications. The purpose of this paper is help child care health consultants sort through the science and the hype with the goal of discovering how the emerging field of developmental neurobiology may inform us in our efforts to provide the best to the children in our care.

In this paper we will:

- Provide a basic overview of how the brain develops from conception to school age, including the basic principles of brain development.
- Explore a variety of factors that may affect the development of the brain, for better and for worse.
- Suggest some practical implications of this knowledge for early childhood programs.

As we proceed through the paper, we will refer to specific research and findings. This will help the reader understand the source of the recommendations for practice. It is important to bear in mind that scientific study is a process rather than a product. This is a rich, active, and expanding field of study and, as such, our understanding is continually evolving. Some believe that neuroscience findings must be narrowly interpreted to protect us from overestimating what we really know (Bruer, 1999).

Although we must always be cautious in our conclusions and open to new information, for the purposes of this document we will examine the subject from a broad interdisciplinary viewpoint. When we discuss brain development, we mean both the growth of the physical brain as well as the elaboration of brain functioning. We will seek to integrate findings from the fields of neurology, neurochemistry, psychology, education, and child development. This interdisciplinary approach fits well with a transactional view of child development, and is increasingly represented in new graduate programs and laboratories across the country. Those programs use terms such as “affective neuroscience,” “psychophysiology” or

“neurobehavioral development” to reflect the complexity of the interfaces among brain, mind, and behavior.

General Concepts

1. All behavior and learning are represented in the brain.

The brain is a natural for interdisciplinary study. This organ has sparked the interest of students of a range of fields from biology to philosophy. Although clearly a biological structure, the brain is also where all human emotion, learning, and behavior are represented. This obvious fact is often treated as a revelation. However, as one down-to-earth preschool teacher commented, “Where else would it be?”

2. Brain functioning is influenced by the interaction of genetics and experiences.

Neuroscientists are gradually discovering some of the specific ways that a person’s environment interacts with biology to produce a variety of developmental outcomes, including brain functioning. Recent research indicates that experience is needed to “turn on” selected genes, thus shaping the expression of genetic characteristics. This dance of biology and experience is an intricate, complex and continually interactive process that probably continues throughout life.

3. The brain continually grows and changes in response to experience.

Neuroscientists call this characteristic “plasticity.” It is most apparent in the early years of development, but it continues throughout life. Although many organ systems respond to environmental stimuli with structural and/or functional modifications, the brain may be the organ that is the most adaptable.

4. The human brain is “unfinished” at birth.

Many of the body’s organs are mature at birth. A healthy newborn’s heart and lungs work much like those of an adult – only smaller. The brain on the other hand completes its structural and functional development largely after birth. During the first few years of life, the brain forms many connections between brain cells, as well as developing cells that insulate and support those connections.

5. Understanding how the young brain develops and functions can help us promote optimal development.

Because experience and other environmental factors have an impact on how the brain grows and develops, knowledge of that process gives us guidance on how we can help children achieve the brains they will need for happy and successful lives.

Basic Brain Structure

We will use a simple triune model (brain stem, limbic system, and cortex) to discuss the basic structure of the brain. The brain develops from the inside out. The first and most basic structure to form is the brain stem. Sitting right at the top of the spinal column, the brain stem is responsible for managing the biological functions that keep us alive, such as respiration, heart rate, and blood pressure.

Nestled just above the brain stem is the limbic system – often referred to as “the emotional brain.” This is where the basic survival instinct appears to originate, including fear, rage, sexual urges, and the drive to associate with other human beings. The limbic system is composed of a host of interactive structures that work together to regulate our responses to stress and threat – that “fight or flight” response we learned about in high school biology. When neuroscientists refer to the HPA system (hypothalamic-pituitary-adrenal axis), they are referring to the way the hypothalamus (in the limbic system) secretes a releasing hormone which causes the pituitary gland to release its stimulating hormone which in turn prompts the adrenal cortex to release cortisol. This system’s development appears to be influenced by the pattern of stress a child experiences in his or her first few years of life and whether it is followed by comforting from the primary caregiver (Schore, 2001a: 2001b).

The last part of the brain to complete development is the cerebral cortex (also referred to as the cortical area). The cortex actually wraps around the deeper structures of the brain. Various areas of the cortex are given different names and serve different functions. The part of the cortex toward the front of the brain (behind your forehead) is called the frontal cortex. The very last part of the frontal cortex to develop is the prefrontal cortex. The cortex is sometimes called “the executive brain.” This is where many higher level functions are processed, including problem-solving, predicting consequences, inhibiting action on emotional impulses, and planning behavioral responses, and which we now know is still developing late into adolescence.

So how do these three primary areas of the brain develop? Shortly after conception, as cells begin to divide, a neural tube is formed which eventually becomes the spinal column. At one end of this, cells cluster to form the brain stem. The basic brain cells are called neurons. As neurons are produced, they begin to migrate upward and find the places where they belong in the brain. In this way, the brain grows “from the inside out.” By the time a healthy, full-term baby is born, about 100 billion neurons have formed and found their proper locations in the brain stem, limbic system, and cortex. This is essentially the same number of neurons as in the adult brain. However, the baby’s brain at birth is only 25% of the adult brain’s volume. By age five, that volume will increase to 90% its eventual adult size. The most dramatic part of this growth involves the formation of connections between neurons.

Brain Connections

Imagine that you have a city where every home has a telephone, but no one has installed the wiring between the phones. No communication can take place. However, once the phones are wired together, people can talk to one another. In fact, depending on the complexity and expanse of connections, they can have call waiting, conference calls, and other sophisticated ways to communicate. Similarly, during infancy and early childhood, the brain is busy “hooking up” all the neurons to one another in ways to facilitate the brain’s functioning.

Despite the way we talk about the “wiring” of the brain, these connections are not literally wired together. Instead, electrical impulses travel between neurons over tiny gaps called synapses. Chemicals called neurotransmitters help the impulses jump smoothly over the

synapse. Each neuron has a branch that sends electrical impulses (axon) and branches that receive (called dendrites). Immature neurons have fewer synapses, or connecting pathways. Mature neurons can have thousands. In some ways, you can compare the growth of these neuronal connections to the growth of a tree. Imagine that the trunk of a young sapling is the axon, branching into a few root structures. The few branches overhead are like the dendrite spines. As the tree grows and matures, the growth continues to branch off, both overhead and at the roots. In addition, bark grows to protect the trunk. In our analogy, this bark is similar to the insulation that surrounds the axon to insure that the electrical signals move smoothly and efficiently. This insulation is called the myelin sheath, and the process is called myelination.

Neuroscientists believe that some of these connections are “programmed.” They call these “experience-expectant” connections. Experience-expectant connections grow spontaneously at given times, ready to receive the expected experience. One example is vision. In the first months of life, the brain produces connections that expect to receive visual input. However, if that visual input is not received (for example, due to an untreated cataract that prevents light from entering the retina), the connections are reabsorbed into the cell. In the case of vision, scientists have discovered that once a sensitive period of development passes without the needed experience, the brain loses the ability to form the appropriate connections. This is the research that gave rise to concerns about “critical periods” and “windows of opportunity” for brain development. Actually, definitive evidence for clear critical periods in brain development exists only for some sensory systems, particularly vision and some auditory discrimination (Bailey, 2002).

Scientists use the term “experience-dependent” to describe the kind of connections that form and are maintained in response to experience, or environment. For example, brain scans of professional musicians show more activity (or connections) in the part of the brain reflecting the control of the fingers involved in playing their instrument, as well as in the auditory cortex (Pantev, Engelien, Candia, & Elbert, 2001). These connections did not grow “expecting” that the user would be playing a musical instrument. Rather, the long years of practice and training are thought to trigger and then solidify the related motor and auditory connections. Many of the connections in the cortical part of the brain are thought to be experience-dependent.

Another far-reaching and influential discovery about brain connections was made by a neuroscientist named Peter Huttenlocher (1995). He found that, rather than increasing in a steady upward progression of brain growth, the number of synapses actually “overgrow” during the early years of life – then the developmental process is finished by the spontaneous “pruning” of about half of those connections. Scientists estimate the following pattern of growth:

- At birth – about 50 trillion synapses
- By age 3 – about 1,000 trillion synapses
- By age 18 – about 500 trillion synapses

This dual process of proliferation and pruning is a commonly misunderstood phenomenon, with some people believing that we should try to help the child “keep” more connections. Another faulty belief is that the number of connections represents intelligence or learning capacity, and, as a result, we must actively “teach” children all we can during this fertile period of growth. Actually, selective elimination is a critical part of the maturation of the brain. There is some evidence that this pruning process is faulty in children who are affected by disorders such as fragile X syndrome (Irwin, Galvez, & Greenough, 2000). These children have been found to maintain more of these early connections into adolescence and beyond.

It appears that healthy development proceeds by pruning faulty or unused connections while the remaining connections are strengthened and streamlined. In this way, each individual can grow the brain that is most useful for his or her particular environment. Our real challenge during this period is to create an environment that provides active use for the kinds of connections that we want children to refine and keep for the future.

Factors that Influence Brain Development and Function

Biological Environment

A healthy pregnancy provides the best environment while neurons are forming and migrating to their appointed locations. Depending on when the developing fetus is exposed, numerous factors can adversely affect the process. Those factors include malnutrition, drugs (both legal and illegal), environmental trauma, toxins, and infections.

Environmental air quality is an important issue for all of us, but in pregnant women, the quality of the air they breathe has a direct influence on fetal development. Research has linked maternal smoking to attention deficit hyperactivity disorder (ADHD) in children (Sadowksi & Parish, 2005).

Maternal stress is another aspect of pregnancy that is known to influence fetal development. There is evidence that maternal exposure to extreme or chronic stress causes high levels of a stress hormone called cortisol which increases risk for prematurity and low birth weight, as well as affecting the developing nervous system (Sandman, et al., 1999).

After a baby is born, many of the same factors continue to be important. In addition to good nutrition, the love and support of a caring adult and protection from adverse substances, the child’s optimal brain functioning depends on adequate oxygen, hydration, and blood flow. Other biological risks that affect significant numbers of children include:

- Lack of adequate sleep. Many young children are operating on a sleep deficit, and research indicates that sleep adequacy and quality are strongly related to neurological functioning and behavior regulation (Sadeh, Gruber, & Raviv, 2002). Recent research also suggests that certain sleep cycles are critical to the brain’s ability to consolidate experiences into learning and memory, although there is disagreement about these conclusions.

- Second-hand smoke. About 40% of US children are exposed to someone smoking in their home. School-aged children exposed to even low levels of smoke have lower scores on measures of reading, math, and reasoning skills (Yolton, et al., 2005).
- Lead exposure. As the research data collect, we are increasingly aware that exposure to even very small amounts of lead affects brain function and development (Canfield, et al., 2003). Exposure to lead can result in a variety of effects including impairment in general intellectual functioning, attention deficits, speech and language disorders, problems with learning and memory, high activity level, reduced problem solving, and poor behavioral self-regulation.
- Head injury. Shaking a baby can cause a particularly dangerous brain injury and result in death or permanent disability (Karandikar et al., 2004). The brain is actually bruised by bouncing back and forth against the skull, causing global injury. In addition, other kinds of head injury can cause damage to the brain. Some research indicates that even minor blows to the head can cause subtle kinds of brain injury resulting in attention, emotional, or learning problems.

Sensory Environment

Just as Piaget noted by observing infant behavior many years ago, neuroscientists tell us that a child's sensorimotor areas are the first parts of the brain to be developed. These areas complete the process of myelination by around age five – one measure of development and maturation. For this reason, it is important that opportunities for motor and sensory experiences be available to the young child. Equipment such as walkers, wind-up swings, and baby carriers all limit the child's ability to actively seek kinesthetic and proprioceptive input.

One often-cited animal study (Greenough, 1987) found that rats that were raised in cages with a variety of toys, wheels, mazes, and other kinds of "enrichment" had more cortical density than their peers who were confined to the typical lab cage. Although rats of all ages benefited, the scientists saw the strongest effect in young rats.

Just as it is important to make sure infants and young children have access to interesting things to see, hear, touch, smell, and otherwise explore, it is also important to protect the developing brain from chronic overstimulation. Being exposed to continuous excessive, distressing, or confusing stimulation can inhibit a child's ability to develop auditory discrimination of sounds, as well as creating general stress, irritability or withdrawal. Under such conditions the nervous system is designed to protect itself by protesting (through irritability or fussiness) or by shutting down ("zoning out"). Nothing can tell you the "right" level of stimulation for any given child except that child's responses. This brings us to one of the most important influences on early brain development – the child's relationships with his or her primary caregivers.

Early Relationships

The most important prerequisite of a baby's survival is his or her connection with an adult caregiver. This process of developing a special, trusting relationship is called attachment. That relationship serves many functions, but there is increasing evidence that the qualities of

such early relationships influences the way a child's brain develops, particularly the part of the brain that involves physiological, emotional and behavioral self-regulation. Developmental, psychological, and neurological research evidence all converge on the importance of sensitive, responsive, and emotionally positive interactions in a child's development.

One collaboration of neuroscientists, physicians, and social scientists has released a report, *Hardwired to Connect* (2003), suggesting that a recent upsurge in mental health problems in children may be traced to the lack of opportunity to form the kind of interpersonal connections that are needed for optimal development. The National Scientific Council on the Developing Child has released a recent series of working papers that highlight the importance of relationships and emotion to early brain development (2004).

Since early relationships are so important, anything that interferes with a parent's or caregiver's ability to respond to a child in a loving, positive, sensitive ways is a risk to that child's development. Very young children tend to "mirror" the emotional cues of the adults they depend on. Mothers who are depressed tend to be less emotionally available to their children. There is some evidence that this influences the way the child's brain processes emotions, resulting in more "withdrawal" activity and less "approach" activity. This pattern of brain activity reverses when the mother's depression lifts and she is more engaged with the child (Dawson, 1992; 1994)

Another significant risk factor within early relationships is the presence of child maltreatment, domestic violence, parental substance abuse, or other frightening interpersonal experiences. Repeated activation of the developing child's stress response system appears to sensitize the system to stress. As a result, the part of the brain that responds to threat becomes very reactive. In some cases, this can produce lasting changes such as a high level of emotional reactivity or a tendency to "disconnect" from interaction.

Much of the research regarding the importance of interaction is focused on parent-child relationships. However, many children spend much of their early lives with substitute caregivers – child care providers, babysitters, or relatives. Those relationships also influence development. In fact, the quality of a child's relationship with a caregiver may be the single most important factor for overall quality of care. One researcher, Carolee Howes, has studied the impact of children's attachments to their child care providers and summarized ten years of longitudinal findings in her book, *A Matter of Trust* (2002).

We know that secure and responsive mother-child interactions are important to a child's ability to explore and learn. Howes (2002) found that children form similar attachments to their child care providers, and those relationships influence behavior and development. Toddlers and preschoolers who had warm, secure attachments to their teachers engaged in more competent exploration and cognitive activity in child care. They also had fewer behavior problems and got along better with peers. Even more striking, early teacher-child relationships seem to give the young child a kind of model for relating to subsequent

teachers. Secure attachment to the *first* child care teacher are associated with a trusting relationship with the same child's elementary school teacher at age nine!

Practical Implications for Child Care

1. Health standards (such as those outlined in Caring for Our Children, 2002) regarding safety, nutrition, adequate sleep, and opportunities for active play support brain development as well as general child health.

Because the brain is a biological organ, it needs the same ingredients for growth and protection that the rest of the body needs. The sensory systems such as vision and hearing are particularly important during the early months and years of life, as those connections are formed in the brain. Early identification and treatment of health, vision, and hearing problems are critical.

2. Young children need to be free to pursue a variety of sensory and motor experiences in the context of a safe, encouraging environment.

No extraordinary materials are necessary to provide an environment that nourishes the brain. In fact, the active-learning, whole child approach that was advocated by early preschool and kindergarten theorists years ago is exactly the kind of environment that promotes early sensorimotor connections in the brain. Healthy children have an inborn drive to experiment and learn in their environment. Our job is to keep that environment safe and share the joy of moving, exploring, and learning within each child's individual style.

3. Fostering individual, stable, warm, and supportive relationships between children and caregivers should be a top priority within child care settings.

There is far more neurodevelopmental research supporting the importance of early relationships and emotion than there is supporting an emphasis on early cognitive functioning. Just as the limbic system (remember, the "emotional brain") is a more basic and primitive structure than the cortex, a child's emotional well-being is a more basic and fundamental need. Optimal cognitive exploration and learning depend upon the quality of secure, early relationships. Given the importance of continuing secure relationships, child care policies and procedures that encourage continuity of care, small group size, and small child to teacher ratios should be strongly encouraged.

4. The "curriculum" of the child care setting should include social emotional development as an integrated core component.

Although the "new brain research" has been co-opted by marketers to promote all sorts of gadgets for "stimulating" cognitive development, the actual body of research provides far more support for the importance of social emotional growth during the infant, toddler, and preschool years. In fact, our knowledge of brain development suggests that experiences that integrate positive emotions, relationships, sensory inputs, and cognition are the ones that will be most likely to create enduring and meaningful learning within the brain. Interestingly, that is exactly what developmental research has told us for many years!

5. *The child care setting can be a point of support for families in understanding and meeting their child's need for positive emotion and loving interaction.*

Like the child's health care provider, the child care provider is the only person outside the immediate family who provides parents with information, support, or understanding about their relationships with their children. A strong collaborative relationship with each parent can help children feel secure, as well as promoting the family's well-being. Providers can help parents reframe their children's negative behaviors into opportunities for modeling and encouraging the coping skills that begin to develop in the frontal cortex during these years.

6. *Child care staff have tremendous power in influencing a child's development, but not all children need the same things.*

Because of the continuous interplay between the child's biological and genetic makeup and his or her environment, the experiences provided within the child care setting can have a significant impact on the way nature unfolds within a given child's brain. Child care providers are responsible for structuring the experiences of children while the initial framework of the brain is being built. The possibilities for influence are likely to be relatively more powerful during this period. Our challenge is to provide the kind of environment where a child practices the emotions, behaviors, and interactions that we want to strengthen and sustain.

Each child brings a unique combination of temperament, experiences, biology, and other factors that causes him or her to respond to the child care environment differently. That is why individual relationships are so critical. A caregiver must really know and care about a child to be able to respond to that child in individual ways.

Resources for Further Exploration

Additional Reading

Science, Policy, and the Young Developing Child: Closing the Gap Between What We Know and What We Do (2004).

Jack Shonkoff, MD, Dean of the Heller School for Social Policy and Management, Brandeis University, outlines the policy implications of what we know about the developing child.
<http://www.ounceofprevention.org/downloads/publications/shonkoffweb.pdf>

Young Children Develop in an Environment of Relationships (2004).

National Scientific Council on the Developing Child. Concludes that “relationships are the ‘active ingredient’ of the environment’s influence on healthy human development. Includes extensive research references.

http://www.developingchild.net/papers/paper_1.pdf

Children’s Emotional Development is Built into the Architecture of Their Brains (2004).

National Scientific Council on the Developing Child. Concludes that “it is essential young children’s feelings get the same level of attention as their thinking.” Includes extensive research references.

<http://www.developingchild.net/papers/workingpaperII.pdf>

Nature, Nurture and Early Brain Development (2001).

University of Missouri-Columbia Extension Service. An easy-to-read discussion of early brain development and child care. Includes illustrations of immature and mature neurons.
<http://muextension.missouri.edu/explorepdf/hesguide/humanrel/GH6115.pdf>

Understanding the Effects of Maltreatment on Early Brain Development (2001). National Clearinghouse on Child Abuse and Neglect, HHS. Provides an excellent overview of how and why early stress, abuse, or trauma can have lasting impact on the developing brain.

<http://nccanch.acf.hhs.gov/pubs/focus/earlybrain/>

Research Sampler (2003).

Encouraging Connections™ Provides brief, simple-to-understand summaries of selected research studies, along with the original source citations.

<http://www.encouragingconnections.com/resources/sampler.html>

Low Priced Videos for Consultation and Training

[Ten Things Every Child Needs](#) \$14.95

[I Am Your Child video series](#) \$59.00 for set of seven videos

Websites with Helpful Resources

[Brain Connection](#)

[Center for Early Education and Development](#)

[Center on the Social and Emotional Foundations for Early Learning](#)

[Parents Action for Children](#)

[School Readiness Indicators Initiative](#)

[Talaris Research Institute](#)

[Zero to Three](#)

Recommended Books on Neuroscience and Related Child Development

- Barnet, A.B. & Barnet, R.J. (1998). *The Youngest Minds: Parenting and Genes in the Development of Intellect and Emotion*. Simon & Schuster.
- Bowman, B.T., Donovan, M.S., & Burns, M.S (2001). *Eager to Learn: Educating Our Preschoolers*. National Academies Press.
- Butterfield, P., Martin, C., & Prairee, A. (2004). *Emotional Connections: How Relationships Guide Early Learning*. Zero to Three Press.
- Eliot, L. (2000). *What's Going on in There? How the Brain and Mind Develop in the First Five Years of Life*. Bantam.
- Gerhardt, S. (2004). *Why Love Matters: How Affection Shapes a Baby's Brain*. Brunner-Routledge.
- Gopnick, A., Meltzoff, A.N., & Kuhl, P.K. (1999). *The Scientist in the Crib: Minds, Brains, and How Children Learn*. William Morrow & Co.
- Hirsh-Pasek, K. & Golinkoff, R.M. (2003). *Einstein Never Used Flash Cards: How Our Children Really Learn – and Why They Need to Play More and Memorize Less*. Rodale.
- Howes, C. & Ritchie, S. (2002). *A Matter of Trust: Connecting Teachers and Learners in the Early Childhood Classroom*. Teachers College Press.
- Shonkoff, J. & Phillips, D. (2000). *From Neurons to Neighborhoods: The Science of Early Childhood Development*. National Academies Press.
- Siegel, D. J. (1999). *The Developing Mind: Toward a Neurobiology of Interpersonal Experience*. Guilford Press.
- Siegel, D. J. & Hartzell, M. (2004). *Parenting from the Inside Out*. Tarcher.

Brain Development Glossary*

Amygdala: This part of the brain is involved in our emotions, emotional learning, and memory. Each hemisphere contains its amygdala, shaped like an almond and located deep in the brain, near the inner surface of each temporal lobe.

Axon: The part of the neuron that transmits messages to other neurons, muscles, or glands of the body.

Brain: An oblong organ with folds, furrows, and a fissure or groove down the center. This groove separates the brain into two hemispheres. A baby's brain triples its weight in the first few years of life and quadruples in size by the time a child becomes an adult. This gain is not due to addition of new brain cells (most of which form before birth), but rather, to the massive growth, branching, and increased connections among individual brain cells.

Brainstem: The lower part of the brain that includes the medulla, pons, midbrain, and cranial nerves. It directs our reflexes, vital signs, and automatic control of the eye, face, and head. It also helps us interpret basic sensations involving taste, hearing, vision, and balance.

Brain Imaging: This process involves taking pictures of the brain. The most recent technologies can take images of areas that are especially active while the brain is processing specific types of information, for example, sound or visual input. Three examples of the technology used in imaging are called Positron Emission Tomography (PET), functional Magnetic Resonance Imaging (fMRI), and computerized tomography (CAT scans). Analysis of the electroencephalogram (EEG) is another way to study brain activity.

Central Nervous System (CNS): Term used to refer to the brain and spinal cord together.

Cerebral Cortex: The cortex is the "highest" region of the brain, both in location and function, that is, it controls the lower, older, more automatic parts of the nervous system. The prefrontal cortex, located behind the forehead, is linked with making decisions and judgments, as well as modulating emotional tone.

Cortisol: Cortisol is a hormone secreted by the adrenal gland, which increases during times of perceived stress. Like many hormones, it circulates through the bloodstream to the brain, and so can regulate the activity of brain areas that respond to stress.

Critical Period: A developmental phase in which the brain requires certain environmental input or it will not develop normally. Scientists have documented critical periods for the presence of certain nutrients (e.g., folic acid, iron, protein and calories) and for certain types of sensory stimuli (such as vision and speech sounds). However, there are many mental skills, such as reading, vocabulary, and the ability to see color, which do not appear to pass through tight critical periods in their development.

* Adapted from ZERO TO THREE's BrainWonders (www.zerotothree.org/brainwonders/glossary.html)

Dendrites: These neuron branches are the major receptive surface of the neuron, receiving and

Glial Cells: The word "glial" comes from a Greek word meaning "glue." These supporting cells form a protective coating and nourishment for neurons. They are also essential in providing structural support ("scaffolding") for growing and developing neurons. Glial cells multiply throughout the human lifespan.

Limbic System: This network of interconnected structures is located deep within the brain, just above the brain stem. It plays an important role in human emotion, learning and memory.

Lobes: The four areas of the brain that are demarcated by major fissures (grooves in the surface of the brain). The occipital lobes, located in the back of the brain, are primarily responsible for vision. The frontal lobes are involved in movement, complex judgment, emotional regulation, problem solving, decisions, planning, and creativity. The parietal lobes, in the upper left and right sides of the brain, are involved in higher sensory-motor coordination and language functions. Temporal lobes located above and behind the ears on the left and right sides of the brain are involved in memory, hearing, language, and emotion.

Myelin: A butter-like insulation [greasy coating] around the nerves [axons]. Myelin enables nerves to quickly conduct electrical impulses from one brain area to another. Without myelin, the nerves work sluggishly and inefficiently.

Myelination: The process by which myelin is laid down on the nerves of the brain. At birth, most of the brain lacks myelin, which is an important reason why newborns are so comparatively helpless. As different parts of the brain myelinate, the function of that particular area (e.g., vision, movement, language) makes sharp gains.

Neural Tube: Origin of a baby's entire brain and spinal cord, which forms during the fourth week after conception. First, the neural plate elongates into a *neural groove*. Then the groove zippers shut in two directions, beginning in the middle of the embryo and progressing both towards the head and towards the "tail" end of the embryo.

Neurons: Brain cells that store and send information. There are about 25 types of neurons in a human brain, but they all consist of a *cell body* (which produces energy and makes chemicals to sustain the neuron); *dendrites* (tree-like branches that receive signals from other neurons); and an *axon* (a very long, branching cable that communicates signals to other neurons).

Neurotransmitter: A chemical that carries signals between brain cells. Neurotransmitters are released from packets located at the end of one neuron (the *presynaptic* cell). They then diffuse across the synapse, where they bind to special molecules called *receptors*, located on the outer surface of the next neuron in the chain (the *postsynaptic* cell). This binding stimulates electrical activity in the postsynaptic cell, which in turn releases neurotransmitters from its synaptic terminals. This chain of electrical-chemical activity carries signals from one

brain area to another, such as from sensory areas (eyes, ears, skin, etc.) to the brain, and from the brain to the muscles. Some familiar neurotransmitters are acetylcholine, serotonin, dopamine, and glutamate.

Plasticity: The brain's ability to change as a result of experience or injury. The term derives from the original meaning of "plastic" as "a moldable or pliable material." The human brain remains plastic throughout life (which is how we are able to learn new facts or skills at any age), but it is massively more so in early life. Scientists believe that harmful behaviors or neglect in early life can affect the brain, leading to lifelong problems. A healthy and caring environment, however, can create opportunities for the child to develop to his or her full potential.

Proliferation: The phase in which a child's number of synapses exceeds the number present in adulthood. Although babies are born with relatively few synapses in the cerebral cortex, the number surpasses adult levels in just the first year of life, remains elevated throughout most of childhood, and finally declines to adult levels by the onset of puberty. This decline is a result of *synaptic pruning*.

Proprioceptive: Refers to the sensory receptors, found chiefly in muscles, tendons, joints, and the inner ear, that detect the motion or position of the body or a limb by responding to stimuli arising within the organism. Your sense of proprioception tells you how your body is moving in space, even when your eyes are closed.

Pruning: A process in brain development whereby unused synapses (connections among brain cells) are shed. Between about 2 and 10 years of age, a child's brain has about twice as many connections as an adult's brain. During the pruning phase, a child's experience and environment decide which synapses will be shed and which will be preserved.

Synapses: These are tiny spaces, or connections, between neurons through which nerve impulses travel. In the womb and during the first years of life, many more synapses form than a baby will use as an adolescent and adult. In time, unused synapses wither and die off. Those that survive grow stronger from being stimulated. The largest number of synapses is present between about one and ten years of age. In later life, the rate of production of new synapses seems to be about equal to the rate at which synapses are pruned, or perhaps slightly slower (so that there is a net loss of synapses as we age). Those that remain presumably process information more efficiently.

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