1

Figure 1.1 Matthew: Newborn

The Basic Biology of Brain Development

The brain is without doubt our most fascinating organ. Parents, educators, and society as a whole have a tremendous power to shape the wrinkly universe inside each child's head, and, with it, the kind of person he or she will turn out to be. We owe it to our children to help them grow the best brains possible.

—*L. Eliot (1999)*

Brain Briefing

Although the brain is the least developed organ at birth, the baby has already started making connections to Mom through both smell and sound (Rodriguez, 2007).

Brain development begins shortly after conception. Yes, Jack's brain was busily creating itself from what is called the neural tube (Figure 1.2). This tube closed after about three weeks of gestation and proceeded to form itself into the miraculous structure we call the brain. Neurogenesis, the birth of neurons, proceeds rapidly. Since a baby is born with 100 billion neurons, they must be growing at a rate of over half a million per minute! (Eliot, 1999)

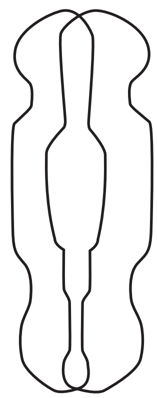


Figure 1.2 The Neural Tube That Will Form Into the Central Nervous System

The neural tube is made up of cells that will give rise to the central nervous system. There are two different types of cells of which to be aware. **Neurons** are the brain cells that do most of the communicating in the brain and that we associate most with learning. **Glial** cells are support cells. They remove unneeded debris, and some literally wrap themselves around the output fiber of the neuron known as the **axon**. This white, sticky wrapper is called the **myelin sheath**. Myelin reinforces this message-sending appendage so that information moves faster and more securely. Besides having an axon that can send messages, neurons have **dendrites** to receive messages. Dendrites are the fibers that receive the information that has been sent out through another neuron's axon. Remember: In through the dendrite; out through the axon! (Figure 1.3)

So, here we are with this teeny brain developing from the embryonic stage through the fetal stage. As the brain forms from the neural tube, neurons **migrate** to specific areas to learn to perform interesting tasks. For instance, some go to the occipital lobe in the back of the brain and become visual neurons. It is during this

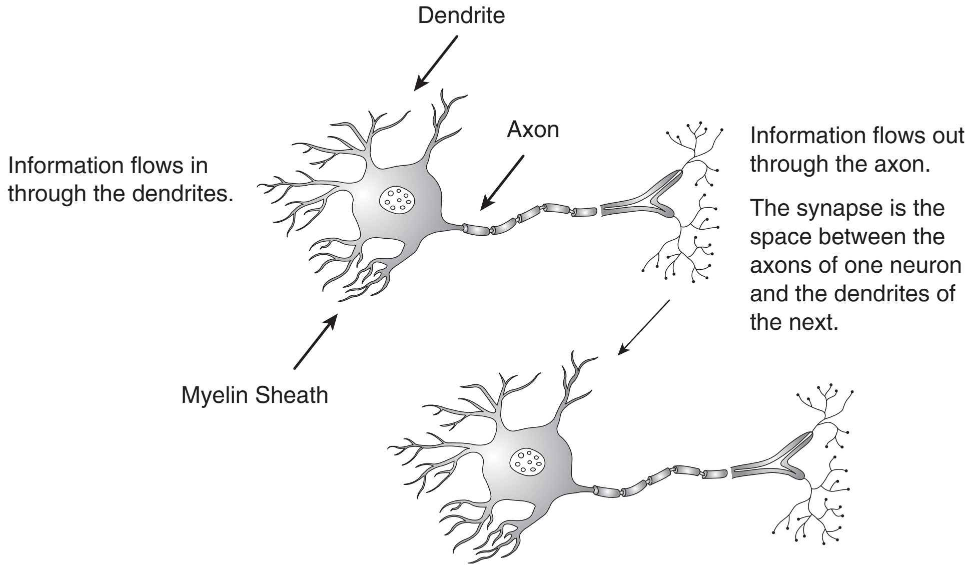


Figure 1.3 Neuron

migration that the brain is highly susceptible to toxins such as alcohol. A pregnant woman drinking alcohol at crucial times can cause the neurons to change their migratory pattern. One result of this can be fetal alcohol syndrome.

These brain cells migrate to become specific structures in the brain, from the brain stem that receives incoming sensory information (except for the sense of smell) all the way up to the neocortex that does our higher levels of thinking. The neocortex, also called the cerebral cortex, makes up about 80 percent of the brain's volume (Figure 1.4). It is the outer layer of the brain that we sometimes call our gray matter.

Beneath the neocortex is a subcortical area called the limbic system. It consists of the thalamus, hypothalamus, hippocampus, and amygdala. The hypothalamus deals with internal communication between the body and the

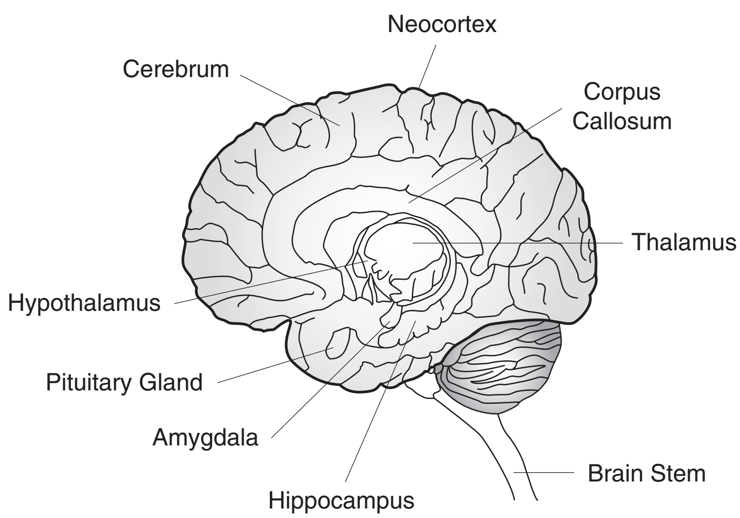


Figure 1.4 View of the Brain

brain. The thalamus is a relay station for incoming information. It sends the messages to the appropriate places in the brain.

In particular we will follow the growth of

- the **hippocampus,** which helps us form long-term factual memories.
- the **amygdala,** which filters all incoming information for emotional content.
- the **corpus callosum,** which connects the two hemispheres of the brain.

The brain is divided into a left and a right hemisphere. The hemispheres work together, yet each has some specific functions. Table 1.1 lists the information processing functions of each. Emotions and reading are just two areas that depend on the connections or "cross-talk" of these hemispheres (Elias & Arnold, 2006; Kagan & Herschkowitz, 2004).

Table 1.1 Functions of the Two Hemispheres Help Us Determine Specific Child Development Growth as the Two Hemispheres Grow and Connect

Left Hemisphere	*Right Hemisphere*
Logical	Holistic
Details	Big picture
Language: speech, grammar, sounds Expressive and receptive language	Language: prosody, tone
Verbal short-term memory	Sensory image memory
Secondary processing of the expression of pleasurable emotion	Secondary processing of emotional communication: sending of unpleasurable emotional signals; reception of both pleasant and uncomfortable feelings
	Reading body language
Facts	Events
Abstract processing	Concrete processing
Knowledge	Emotional significance of knowledge

Each hemisphere is divided into lobes. The lobes have distinct functions. As we watch the growing brain develop, these lobes will be discussed. The development of each region has its own timetable. With the proper stimulation, the lobes mature to create a unique brain. Figure 1.5 shows the brain's lobes, which include the following:

Occipital lobe. This lobe is responsible for vision. It is usually fully developed by age six.

Parietal lobe. It plays a part in the reception of sensory information. Also, the parietal lobe becomes active when problem solving and some calculations are attempted.

> ***Brain Briefing***
>
> Touch activates many areas of the brain. Premature babies who were not touched and caressed did not develop as well or as fast as those who were (Rodriguez, 2007).

Temporal lobe. This lobe is responsible for hearing, some speech, and some memories.

Frontal lobe. This is the area responsible for controlling emotions, working memory, decision making, future planning, verbal expression, and voluntary movement. The frontal lobe can be further divided. We often refer to the area behind the forehead, which is called the prefrontal cortex. It is here that emotion is modulated, feelings are managed, and attention is focused (Sunderland, 2006).

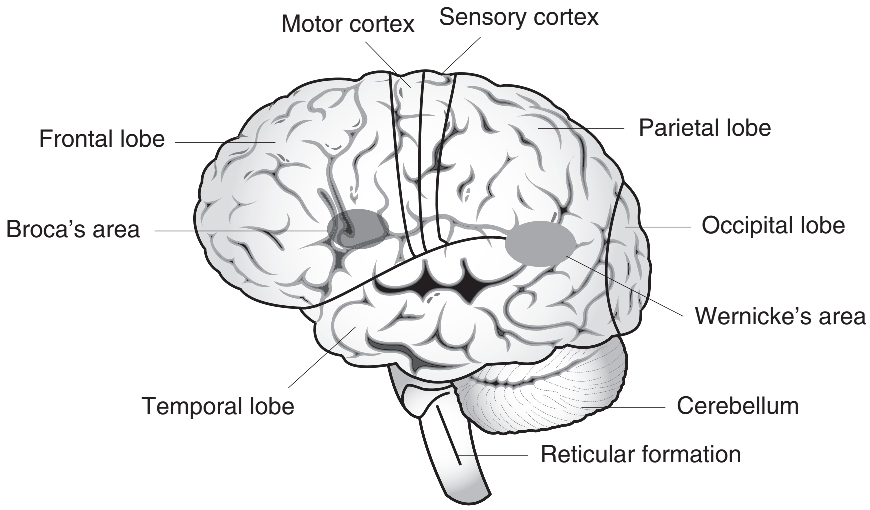


Figure 1.5 Lobes of the Brain

Also in Figure 1.5 you can see two important areas concerned with language and reading. **Broca's area** in the frontal lobe is responsible for expressive language. It puts words together syntactically and grammatically. **Wernicke's area**, in the parietal-temporal lobe, is responsible for receptive language. It stores the mental dictionary with the words and definitions you know. As these areas develop, language and reading skills will increase with proper stimuli.

Finally, notice the **reticular formation** in the brain stem. This structure helps with focus and attention. Its development is related to alertness. This structure helps us filter out some of the incoming information and attend to what we think is important.

Brain Briefing

According to neurologist Judy Willis (2006), it is the reticular formation that is changed by the fast paced media interactions and sensory stimulation that bombard our students. If you feel like you have to entertain your students to keep their attention, it may be due to the rapid pace at which they have to decide what to attend to.

BRAIN CHEMICALS

Early brain development includes the formation and release of chemicals in the brain. These **neurotransmitters** carry messages between neurons. They are released into the space between the sending axon and the receiving dendrites. This space is called a **synapse**, which is a communication point between two neurons (Figure 1.3). In the time between two months of gestation and two years after birth, about 15,000 synapses will form for every neuron in the cortex. The production of synapses as well as the pruning, or cutting back, of synapses is a large part of brain growth and development (Eliot, 1999). As synapses form, they provide more connecting points for dendrites and encourage the growth of **dendritic spines**, small nubs that are able to receive information. The growth of these spines is another indication of brain development. The spine is one half of the synapse, and the axon terminal is the other half. When the spine grows, a synapse is created. If the spine is pruned away, the synapse no longer exists.

The production and release of the following neurotransmitters will cause changes in the brain that will indicate growth and development:

Acetylcholine. Helps with frontal lobe functions and in formation of long-term memories.

Dopamine. Assists in focus, attention, and goal setting.

Norepinephrine. Responds to novelty and aids in memory formation.

Serotonin. Helps control impulsivity, calms the brain, aids in reflective behaviors.

ELECTROENCEPHALOGRAMS

EEGs, as electroencephalograms are called, are used to measure the electrical activity in the brain. We have looked at several chemicals that carry messages from one neuron to another, but the message that is transmitted within the neuron is electrical. For this reason, scientists have been able to monitor the brain's electrical activity and determine where and when this activity is strongest. This is another way to establish brain growth.

Brain Briefing

Human contact and touch promotes a sense of security and encourages healthy brain development. Neural networks grow out of our sensory experiences and begin forming the patterns for learning (Hannaford, 2005).

WINDOWS OF OPPORTUNITY

There are certain time periods when the brain appears to be very receptive to certain types of learning. These periods are called "windows of opportunity," the ideal time to provide the input that these active brain areas require. Simply put, these time periods will involve any or all of the following components:

1. Dendritic growth in a specific area: more receivers of information
2. Synaptic density in a specific area: more space for connections between neurons
3. Myelination of a specific area: faster and easier transmission of messages
4. Increase in brain wave activity

Although these windows do not slam shut, learning is much easier for the brain during these periods. Two windows are considered critical for normal development. Those windows are for vision and speech. If a baby is born with a cataract and it is not removed within the first several weeks of life, normal vision will not develop. That is not to say the child will not be able to see. It does indicate, at least, less than perfect vision. By the age of 12 a child will lose the ability to speak certain phonemes, so this is also a critical window, but one can see that with so many years allowed for development, this window closes slowly (Sousa, 2006).

Brain Briefing

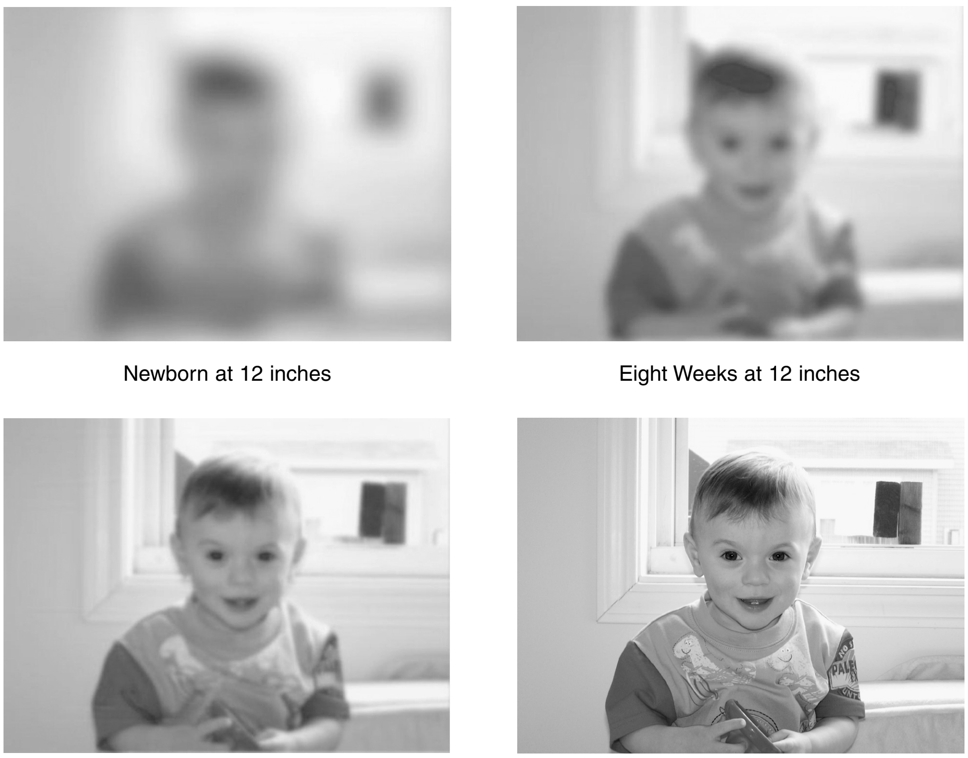
IQ is not fixed at birth. Gone are the days of intelligence tests being able to predict the future for any child. Experience changes the brain (Healy, 2004).

John Bruer, in his landmark book *The Myth of the First Three Years* (2002), helped translate the research on these windows, which are sometimes called critical or sensitive periods. He assured readers that it was unnecessary to panic about these time periods.

Experience Dependent and Experience Expectant

Both neuroscientists and child development experts agree that there are two types of learning that occur (Berk, 2006; Bruer, 2001; Greenough, Black, & Wallace, 1987).

Experience-expectant learning relies on the assumption that circumstances will be present for learning to take place. Neural networks in the brain are expecting to form from specific stimuli that will be present. For instance, vision will develop as the eye is exposed to light and objects. It is expected that this will occur. Disruption of expectant sensory experience at the time the neurons are organizing and growing to meet that experience can cause irreversible damage (Kagan & Herschkowitz, 2004), but not all consequences are permanent. Vision develops slowly in infants, as you can see in Figure 1.6. This figure shows how well an infant can see, at varying ages, from a distance of 12 inches (approximately the distance from a caregiver's face when he or she is cradling a baby).



Newborn at 12 inches

Eight Weeks at 12 inches

Three Months at 12 inches

Six Months at 12 inches

Figure 1.6 This Shows How Well an Infant Can See From a 12-inch Distance

Experience-dependent learning occurs when the brain is exposed to certain types of experiences from the uniqueness of its environment. Neuroscientists often refer to the brain's "plasticity"— its ability to change from experience or from lack thereof. Children who hear the phonemes of their language will learn to repeat them. Those who experience chronic stress may have brains in which development is negatively affected. It is experience-dependent learning that is provided by the home, school, and other environments.

The sensitive periods with their approximate ages of optimal networking and consolidation are shown in Figure 1.7

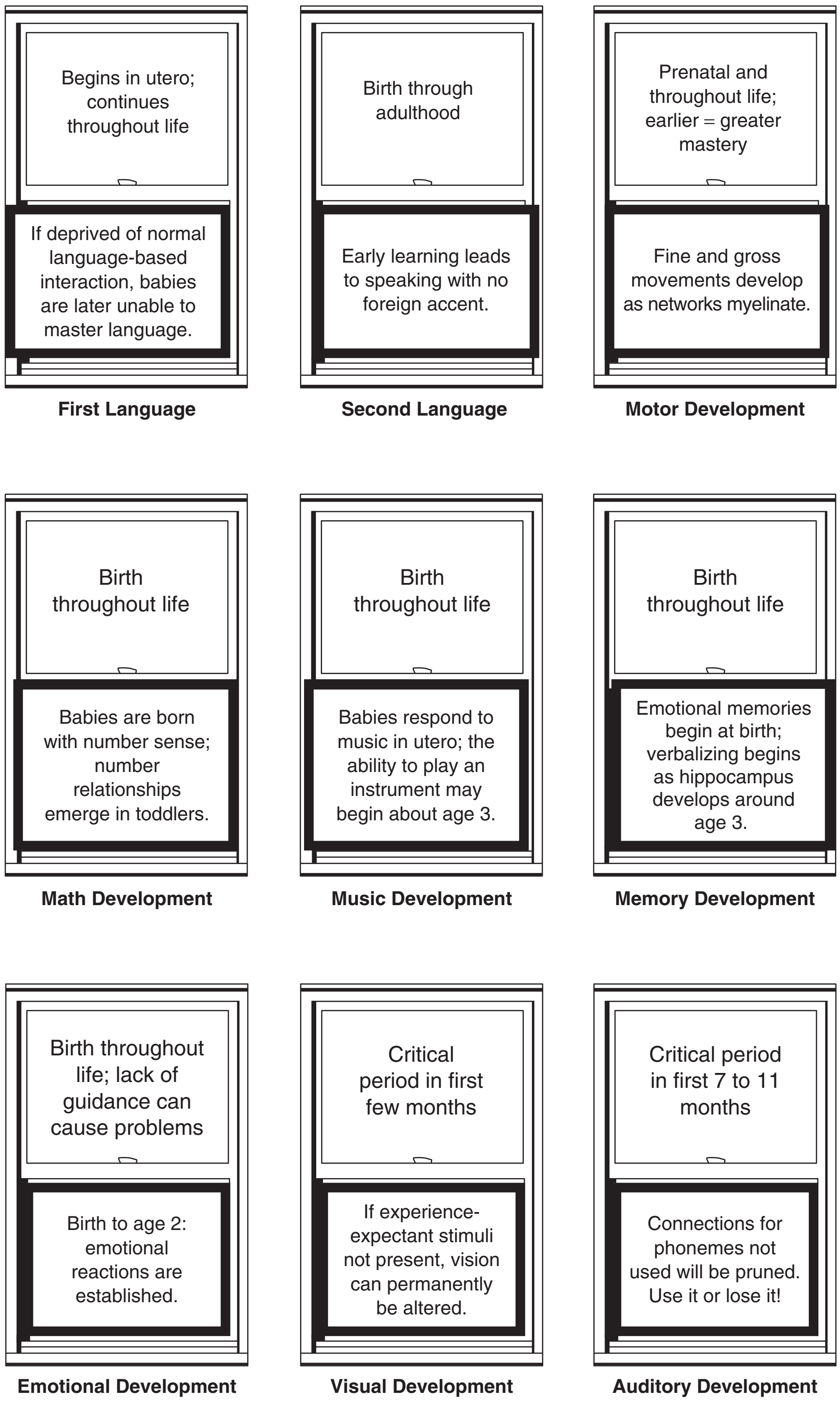


Figure 1.7 Windows of Opportunity: Periods of Sensitivity to Certain Stimuli (Most windows never completely close)

First Language

There is every reason to believe that there are some critical periods for learning one's primary language. From several case studies, it appears likely that sometime between the ages of 6½ and 13, the brain's ability to learn a native language is changed (Bruer, 2002).

> ***Brain Briefing***
>
> There is a famous case of a child called Genie who was kept isolated for 13 years. There was almost no verbal communication, and when she was finally found and released, she had no language skills. As she was properly cared for, she began to learn. Her language skills remained low as she spoke more like a two year old in very short sentences. Brain scans showed little activity in her left hemisphere (Sleeper, 2007).
>
> Other children who suffered similar experiences were found much younger, around the age of six, and learned language quite well (Linden, 2007).

Second Language Learning

As many neuroscientists are studying the brain and learning, some conclusions have been made about the acquisition of a second language. Contrary to some beliefs that students are not ready to learn a second language until they are older, current research suggests that early exposure to a new language appears to be a better time for the brain to assimilate new accents, new vocabularies, and new grammar. Indeed, the brain can take its native language and use what it knows based on similarities and differences to make this learning easier. Yet, it appears that sometime in the second decade of life, it becomes more difficult to acquire such nuances as the appropriate accent (Bruer, 2002; Sousa, 2006).

> ***Brain Briefing***
>
> Children learn their first language through sound, just as baby birds learn to sing by listening to adult birds. The auditory cortex, in the temporal lobe, must receive feedback by listening to others and listening to your own speech. This is also true of second language learning. The more one hears the new language, the better one learns it. Reading and writing the language are not as effective (Rodriguez, 2007).

In my own personal experience with this phenomenon, I taught several children in a family who came from France. The seventh grade twins, who had arrived in America at the age of six, had just the slightest accent on merely a few words. Their younger siblings had no accent whatsoever, but their mom and dad were difficult to understand, as their English was laced with their French accent.

Brain Briefing

In one famous study of Japanese children, it was found that at seven months they could hear the difference between the r and l sounds in English. At ten months, however, their auditory cortex had lost the ability to discriminate between the sounds (Begley, 2007).

Motor Development

Movement begins in the womb. When Amy was pregnant with Jack, she periodically declared he was doing jumping jacks. (Little did I know that this was a play on words; they didn't reveal his name until his birth.) Motor development continues throughout the early years, and actually as adults we can learn new motor skills. If we are to become experts or professionals at a certain skill, the earlier we begin to learn and practice, the better our chances will be at excelling (Sprenger, 2007). My son, Josh, learned this lesson the hard way. Although he was an avid tennis player during the summers of his elementary and middle school years, we couldn't afford to join a tennis club for him to play year round to keep up and hone his skills. When he tried out for the tennis team in high school, he soon discovered that all of the players who made the team had indeed been playing year round.

Memory Development

Emotional memories may be stored from birth, but since the hippocampus is not developed until around the age of three or four, the articulation of such memories is unlikely. Once the hippocampus begins to be involved in memory formation, long-term memory increases. It is at this time that children can tell us stories about their experiences in some detail and after some lengthy periods of time. Memory development continues throughout life if we take care of our brains and practice or rehearse some of the information we want to remember.

Music

There are certainly some mixed reports about the brain and music. It appears from several studies that the brain's response to music involves some of the same neurons that are utilized in math and other problem-solving endeavors (Dodge & Heroman, 1999).

Math

Several studies indicate that infants have some numeric sense. In one recent study involving well-known neuroscientist Michael Posner, it was confirmed that infants as young as six months old can detect errors in mathematics (Berger, Tzur, & Posner, 2006). Recent work at Duke University (Jordan & Brannon, 2006) concludes that babies have an innate number sense as early as seven months.

Emotion

At birth there are several emotional systems ready for survival. According to Sunderland (2006), rage, fear, and separation distress systems form. For this reason, responsive parenting and attachment to a primary caregiver are essential to controlling these systems and allowing the child the opportunity to learn how to calm him- or herself. Diamond and Hopson (1998) say that in the first 24 months, personality, temperament, and emotional reactions are established. Since the emotional system develops faster than the prefrontal lobe that helps control those emotions, it is necessary that someone else's frontal lobe help out.

Emotional development continues throughout childhood and possibly throughout our lives. Emotional intelligence as described by Goleman (1995, 1998; Goleman, Boyzatis, & McKee, 2002) includes the ability to recognize one's emotions, handle those emotions, recognize others' emotions, and handle relationships. These characteristics can begin to be modeled from infancy.

THINKING ABOUT BRAIN GROWTH

As we watch the brain develop in the following chapters, be aware of the following indicators of growth:

1. Synaptic density: More synapses are formed as neurons connect.
2. Myelination: Axons become coated with myelin sheaths.
3. Dendritic growth: New fibers form that receive information.
4. A spurt in production of certain neurotransmitters indicates activity in that area.
5. Increases in glucose consumption signify higher energy levels in the affected structures.

The connection from brain to behavior will depend on the areas that are showing growth. For instance, dendritic growth in the part of the corpus callosum that connects the hemispheres at the frontal lobe might indicate better working memory, higher-level thinking, or perhaps better impulse control.