Brain, Development of

The development of the child's brain is a complex process influenced by multiple factors. From the time the brain starts to form around the third week of prenatal development until the infant is born, billions of neurons, or brain cells, are produced. These neurons are programmed to move to specific locations in the developing prenatal brain and later perform specialized functions associated with their particular location in the brain. While prenatal brain development appears to be mainly determined by biological programs, brain development after birth seems to be greatly influenced by environmental experiences. Postnatal brain development consists of the establishment of interconnections among the billions of neurons. The stimulation that the infant and child receives from the environment determines which connections are formed and which potential connections are lost. Thus, the environment provided by the parents is crucial to the child's current brain development and later behavioral functioning.

About two weeks after conception, the rudimentary beginnings of the brain and spinal cord are formed with the development of the neural tube. The ends of this hollow, open-ended structure begin to close between the third and fourth weeks of pregnancy. Failure of the neural tube to close leads to a class of birth defects called neural tube defects. If the neural tube fails to close at the brain end, a condition known as anencephaly occurs. In this brain defect the cortex of the brain fails to develop, which will either result in a pregnancy not carried to term or an infant who can survive only a matter of days or weeks after birth. Failure of the neural tube to close on the spinal cord end results in a condition known as spina bifida. An infant born with this condition has spinal cord nerves that develop outside the protection of the vertebrae, or backbone. Depending on the severity of the condition, the infant may be born paralyzed or without sensation in the lower extremities. In extreme cases, the development of the brain may also be affected, leading to deficits in cognitive and emotional functioning.

While the timing of the closing of the neural tube appears to be determined by human biological codes, the event is nevertheless greatly influenced by maternal diet. Scientists have discovered that adequate amounts of folic acid, one of the B vitamins, are essential for proper closing of the neural tube. Folic acid occurs naturally in dark green leafy vegetables, orange and grapefruit juice, and fortified cereals. Because the closing of the neural tube occurs so early in prenatal development, it is essential for women to have adequate amounts of folic acid in their diets prior to conception.

After the neural tube closes, brain development proceeds with the mass production of neurons. This proliferation of neurons may occur at a rate of thousands per minute and is more pronounced during the first half of pregnancy. After production, the neurons undergo a process of migration in which they appear to be programmed to move to the various regions within the developing brain. Neurons function with respect to the location to which they migrate, however—not with respect to some prespecified function code. For example, scientists have discovered that if neurons that usually migrate to one brain area in a newborn rat are transplanted into a different brain area of the same newborn rat, the neurons will function as do neurons that normally migrate to that area. While the information for this neuron migration appears to be basic biological code, substances ingested by the mother, such as alcohol, can interfere with neuron movement.
Thus, health professionals advise women to abstain from alcohol consumption during pregnancy.

Neuron production and migration are mainly prenatal events, with most neurons formed by the seventh month of pregnancy. The process of neuronal differentiation tends to occur after birth. During this process the neurons form connections with other neurons and begin to function. Of course, this process begins on some level prior to birth. Scientists know that fetuses startle to loud noises and respond with movement to some stimuli, such as light and sound. Immediately after birth, newborns recognize the sound of their mother’s voice, having heard her voice during the last months of prenatal development. Each of these responses requires a functioning brain, so the neurons do begin the foundation for interconnections during prenatal development.

After birth, brain development is known as a time of “blooming and pruning.” During this process, neurons grow in size and in the means to make potential connections with other neurons. Blooming occurs when the infant’s brain produces many more connections between neurons than can ever be used. It is as if the brain readies itself for any possible pattern of interconnections and functioning. Pruning occurs to the neuronal connections that are rarely or never used and is essential to the development of an efficiently functioning brain. Most child development experts agree that the infant’s environment plays a major role in the formation and strengthening of
Illustrations of the human brain during prenatal development. Drawings are on a common scale, with the first five enlarged on a common scale for detail. During prenatal development most of the neurons in the brain are formed, although the connections among neurons are only beginning to occur. (From W. Maxwell Cowan, "The Development of the Brain," in The Brain: A Scientific American Book. New York: W. H. Freeman, 1979, p. 59)

Connections among neurons after birth. Thus, sights, sounds, touches, smells, and tastes experienced immediately after birth and throughout infancy and childhood contribute to the interconnections among neurons. The result is a brain that rapidly increases in size and weight and processing efficiency.
Advances in the study of brain development in laboratory animals have given great insights into the postnatal brain development in human infants and young children. Much of what is known, or speculated, concerning human brain development has its roots in basic scientific research on kittens and rats. For example, from classic research with kittens, scientists know that there is a sensitive period when the part of the brain involved with vision develops its neuronal interconnections. Thus, when kittens are deprived of specific visual input during the time period when the kitten brain “expects” to receive this input, the kittens show deficits in processing visual information. The blooming occurs with the expectation that interconnections will be formed. When that doesn’t occur within the specified time period, pruning takes place. These research effects are reversible if the visual deprivation is not prolonged. In cases of long-term deprivation, however, brain differences are reported to persist in adult animals.

Classic research with rats also has given scientists great insight into the effects of environmental stimulation on brain development. Rats raised in impoverished laboratory environments [housed individually in laboratory cages] are behaviorally and physiologically different from rats raised in enriched laboratory environments [housed in complex environments with litter mates and periodic toy changes]. Behaviorally, the impoverished rats are more aggressive, take longer to adapt to testing situations, and perform more poorly on learning and memory tasks than the enriched rats. After testing, the rats are sacrificed and the brains examined. Rats raised in enriched environments display greater numbers of connections between neurons than rats raised in impoverished environments. As with the research with kittens, there appears to be a sensitive period for these effects. It was only for preweaned rat pups that scientists observed differences in brain development with exposure to enriched and impoverished environments. After weaning, exposure to the enriched environment has little effect on brain structure.

Child development experts have used this classic animal research to speculate concerning the effects of the environment on human infants and children. Most agree that the environment provided by the parents is crucial for development and that intervention is important for children not exposed to optimal environments. This is the crux of the federally funded Head Start program for children between the ages of three and five. This program, however, has been greatly criticized since its inception in the mid-1960s. The purpose of the program is to provide enrichment experiences for low-income children prior to school entrance, with the goal of decreasing the gap in academic performance between children from lower-income and middle- to higher-income families. Based on research with children in Head Start, these effects appear to be erratic and temporary, however.

It may be that research on sensitive periods for brain development can explain these inconsistent research results for the Head Start program. In the classic research with kittens and rat pups, scientists discovered that the timing of the stimulation determined whether or not there was an effect on brain development. Obviously, these types of studies cannot be accomplished on human infants and children. There are some infants and children from extremely low-income families, however, who experience these types of impoverished environments on a daily basis from birth. Recent research with these impoverished children has led to exciting implications for early intervention with low-income families.
The Carolina Abecedarian Project was begun by Craig T. Ramey and Sharon L. Ramey in the 1970s at the Frank Porter Graham Child Development Center, at the University of North Carolina at Chapel Hill. This scientific study was designed to examine the benefits of very early intervention for children from low-income families. The children came from high-risk families who were characterized by poor, single, teenage mothers who had low IQ scores and little education themselves. The children from these impoverished environments received full-time, high-quality educational intervention (in the form of games) in a group child-care environment from early infancy until the children entered kindergarten. Progress in school was monitored periodically until the children were twenty-one years old.

Children in this early intervention program had higher reading and math scores from elementary school to age twenty-one relative to children from comparable home environments who were not involved in the intervention. The children completed more years of education and were more likely to attend a four-year college. Of course, it cannot be known if there were specific effects on the neuronal connections of these children. The implication, however, is that the early intervention of the Abecedarian Project influenced brain development at a sensitive period for neuronal connections. Thus, “early intervention” appears to mean infancy and not preschool.

The implications from these scientific studies are great with respect to early development and later functioning. The stimulation the infant and young child receives from the home environment is crucial for brain development. Many well-educated parents listen to media reports concerning these types of scientific studies and play Mozart for their infants in an attempt to enhance future math scores. They also enthusiastically purchase books and videos advertised to create brain connections needed for future learning. Although these efforts are admirable, they appear to be unnecessary. The scientific data with kittens, rat pups, and the Abecedarian Project with human infants and children have demonstrated that it is the organism in the impoverished environment, compared to the organism in the enriched environment, that is at risk for deficits in brain development. There is no scientific evidence to suggest any value to increasing the amount of enrichment to children already in an enriched environment. On the contrary, the timing of environmental stimulation appears crucial. Parents who arrange safe, nurturing, and stimulating environments for their children from birth are providing the very enrichment that is essential for optimal brain development. 

Martha Ann Bell

See also Head Start, Early

References and further reading


