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Preschool Policy Brief

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Connecting Neurons, Concepts, and People

Brain Development and its Implications

by Ross A. Thompson, Ph.D.

The past decade has seen an upsurge in public understanding of early brain development. News reports, statements by policymakers, and commercial marketing of products for infants and young children have all contributed to a widespread understanding of the explosive growth of the brain in the early years and that stimulation acts as a catalyst to brain growth. Beyond this, however, most people are unsure what to make of this new knowledge about brain development.¹

This policy brief summarizes what is known about early neurobiological development and corrects some of the common misunderstandings and misrepresentations of the research.



What We Know:

- The most significant advances in brain architecture occur prenatally.
- Brain development is life-long, hierarchical, cumulative, and integrated.
- The brain incorporates experience into its architecture.
- Critical periods are exceptional, not typical, in brain development.
- The developing brain's flexibility declines over time, but some plasticity endures.
- The young mind is astonishingly active, capable, and self-organizing.
- Developmental neuroscience provides much greater insight into the hazards to avoid in brain development than opportunities for enrichment.

Policy Recommendations:

- Government and business should support prenatal and well-child health care, good nutrition, efforts to eliminate children's exposures to harmful pollutants and toxins, and high-quality preschool programs in striving to support healthy early brain development.
- Early prevention is better and less expensive than later remediation. Health care services, early intervention programs, and preschools should ensure that they provide early hearing, vision, language, cognitive, and behavioral screenings, and link children to necessary services.
- Sensitive interactions with adults do more to promote brain development than any toy, CD, or DVD. Preschools should deliver services that enable adults to have rich interactions with children.
- Preschools should embrace educational approaches that encourage child-oriented discovery over adult-directed instruction.
- Since social-emotional and cognitive development are intertwined, preschool programs should recognize and focus on both.
- Exposure to chronic early stress is harmful. Mental health experts can help preschool staff work with children with behavioral problems and learn to identify and refer children and families to other services as needed.

The Science of Early Brain Development

The study of human brain development is still in its infancy. New technologies—electroencephalogram (EEG), positron emission tomography (PET), functional magnetic resonance imaging (fMRI)—are now permitting more direct examination of brain functioning than older approaches that relied on studies of animals or behavioral studies of humans who had experienced brain damage. Still, the new methods, which are less invasive and can produce images of the brain's activity, are best used with older children and adults who can sit still for the examination, and they cannot capture completely all the simultaneous processes of growth and change that happen so quickly in young children. As a consequence, our understanding of the developing brain is based on multiple sources of still-evolving knowledge and is likely to change in the next decade.

The following summarizes the main principles of early brain development, based on the science at this time.² Together, these principles reveal that brain development is the product of an ongoing complex interplay between the child's active mind and the environment, in the context of strong genetic guidance.³

1. The most significant advances in brain architecture occur prenatally.

During pregnancy, the child's brain grows more significantly in size and function than at any subsequent stage of development. While the fetus is in the womb, neurons are produced at an astonishing rate (this process is called *neurulation*)—more than 250,000 per minute during some periods.⁴ The neurons migrate to their eventual destinations within the brain and begin to form axons and dendrites to enable the process of *synaptogenesis*, which is the process by which neurons make connections



with other neurons through the creation of electrochemical junctions.

During this period of rapid development and extending throughout early childhood as development continues, the brain is a vulnerable organ. External hazards, such as viral infection, drug or alcohol exposure, or ingestion of environmental hazards (such as chemicals found in pesticides, air, food, or water; mercury in fish; or lead exposure from peeling paint in old buildings) are associated with a variety of disorders in brain development when these harms are experienced prenatally or in the early years of postnatal life.⁵ Because of the developing brain's high need for energy to fuel its growth, prenatal maternal malnutrition (particularly deficiency in folic acid, iron, and certain other vitamins and nutrients) or postnatal child malnutrition can have devastating effects on the developing brain.⁶ In addition, chronic stress for the mother during the prenatal months and/or for young children are both associated with the infusion of stress hormones in the central nerv-

ous system that in some cases can have damaging effects on children's brain growth.⁷

2. Neural connections develop over an extended period of time that varies for different brain regions.

Synaptogenesis begins prenatally and continues most rapidly through adolescence, although synapses develop throughout life. It occurs earlier for basic sensory and motor areas of the brain (such as the areas associated with vision and hearing), later for brain regions governing receptive language and speech production, and latest for the areas of the brain in the prefrontal cortex that are associated with higher cognitive functions such as reasoning and planning.

The process of synaptogenesis involves two phases. The first is "blooming." Under genetic control, an initial overproduction occurs of synapses distributed across broad regions of the brain. Blooming varies in timing by brain area but, by the

end of the child's first year, the young brain is a very dense organ. The second phase is "pruning." In this phase, a progressive retraction of synapses occurs based partly on experience, which helps determine which synaptic connections are activated and reactivated. Multiple activations help to strengthen and consolidate synaptic connections, while the synapses that are activated less frequently are more likely to be eliminated or reabsorbed.⁸

The timing of these developmental processes parallels changes that can be observed in children's behavior as they grow older. The most essential brain functions such as basic sensory and motor capabilities are consolidated earliest in life, language emerges later in childhood, while higher cognitive processes continue to develop into adolescence. Simpler skills provide the foundation for more sophisticated skills.

It is important to emphasize that healthy brain development requires both overproduction *and* retraction of neural connections. Too many neural connections would ultimately be inefficient, so efforts to increase the number of neural connections in young children through the provision of potentially overstimulating early experiences in highly enriched environments are inconsistent with what is known about brain development.

3. The brain incorporates experience into its developing architecture through synaptic overproduction and retraction.⁹

Synaptic overproduction and retraction allows the human brain to adapt to the requirements of everyday life and to changing environmental conditions.¹⁰ Through experience, the brain becomes a more refined, efficient organ as the neural connections relevant to the skills, language, and cognition for everyday life are strengthened. But the brain's responsiveness to experience also means that during times of rapid brain growth such as early childhood, negative

experiences (such as those associated with chronic, overwhelming stress) can become incorporated into the developing architecture of the brain and possibly result in longer-term negative consequences.¹¹

While we know that chronic stress is bad for the developing brain, we unfortunately know little about the early experiences that are essential to brain development.¹² We do know that early visual experience is necessary to organizing optical brain areas in the occipital cortex,¹³ and language exposure is necessary to organizing brain regions related to receptive and expressive language.¹⁴ But we know much less about the significance of other kinds of experience, especially regarding experiences that might help the organization of brain areas relevant to thinking, problem-solving, and other higher cognitive functions.

4. Critical periods are exceptional, not typical, in brain development.

Critical periods are specific episodes in development when exposure to a particular environmental influence is *required* for healthy development to occur. Although critical periods have been identified for other animal species, and in humans there are critical periods for some basic sensory functions like sight, the complexity of human brain and behavioral development plus the extended periods of synaptogenesis suggest that "sensitive" rather than critical periods are more common. In sensitive periods, the relevant time periods for environmental stimulation are broader and more flexible.¹⁵ The concept of sensitive periods is more consistent than critical periods with existing knowledge concerning the importance of early language stimulation in organizing relevant brain regions, and with behavioral evidence concerning the growth of cognitive functions¹⁶ and social-emotional development.¹⁷ The "window of opportunity," therefore, for stimulating brain growth is wide rather than narrow.

The science of brain development provides an unprecedented opportunity to enhance public awareness and generate support for public policy initiatives that can benefit young children and their families, but such support will quickly disappear if the public concludes that the importance of the developing brain was oversold or the science was misapplied.



5. Brain function is enhanced as neural circuits are myelinated, a process beginning prenatally and extending through adolescence.

Myelination is the process by which portions of the neuron become coated with a protein that improves insulation and speeds neural transmission.¹⁸ Like synaptogenesis, myelination occurs earliest for basic sensory and motor processes, and much later for areas governing sophisticated cognitive skills. The influence of myelination can be observed in infancy, when smoother and more coordinated arm movements replace the jerky swipes of earlier months as myelination enables more efficient neural control of motor movement. In other words, at the same time that blooming and pruning is occurring, neural connections are functioning more efficiently because of myelination.



6. Brain development is life-long.

Brain development begins prenatally and continues into early adulthood, particularly in the development of higher cognitive functions in the prefrontal cortex and elsewhere. The brain has tremendous adaptive flexibility,¹⁹ and neuroscientists have also discovered that new neurons continue to be produced in certain areas of the *adult* brain,²⁰ and new synapses are forged throughout life as a product of experience.

7. The developing brain's flexibility declines over time, but some plasticity endures.

The immature brain is a highly plastic (i.e., flexible and adaptive) organ, capable of incorporating a greater variety of experiences and influences than at later ages.²¹ The infant brain has many more neurons and synapses than does the mature brain, and many have not yet become integrated into broader circuits or specialized functions. This gives the young brain considerable functional potential.

As neural connections become refined and consolidated through experience and as sensitive periods channel brain growth in specific directions, the brain's plasticity declines. For example, newborn infants are capable of discriminating

the speech sounds of all of the world's languages, but this potential is gradually lost as brain regions relevant to language become progressively organized to perceive the speech sounds of the language the child hears at home and will eventually learn.²² With increasing age, therefore, the brain becomes organized and functionally adapted to exercise particular skills and, as a consequence, much of its earlier potential is lost.

An important implication of declining brain plasticity is that it is biologically more efficient to prevent difficulties from arising in brain functioning than it is to try to remediate problems that have already developed.²³ The potential efficacy of early interventions is increased by the greater plasticity of the young brain to adapt positively to such interventions. By contrast, it may be more difficult to remedy problems after they have developed, as the brain's functional organization has become consolidated around early deficiencies. Indeed, the interventions that may be necessary to remediate later problems are likely to be much more costly and prolonged than early preventive interventions. For example, some language-related delays are best treated early in life before language pathways in the brain have been consolidated.²⁴

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8. Brain development is integrated.

The public understands that the brain has functionally specialized areas. What is perhaps less well understood, however, is that the brain is also a highly integrated organ. Many brain regions, for example, are involved in perceiving, interpreting, and responding to emotional cues,²⁵ and multiple circuits are associated with the formation and retrieval of memories.²⁶ The interconnections among brain areas contribute to the brain's functional efficiency.

The best-known example of brain integration is the integration of the cerebral hemispheres. It has long been known that right and left cere-

bral hemispheres of the brain are specialized for somewhat different psychological processes, but the cerebral hemispheres are functionally integrated through the part of the brain called the corpus callosum.²⁷

Similarly, scientists are now learning that as children grow older, certain areas within their brains become better integrated with one another and changes in children's behavior result. For example, as areas of the prefrontal cortex mature, beginning in early childhood and extending through adolescence, they become progressively integrated with earlier-developing brain regions associated with memory, emotion, attention, and other cognitive functions. This results

in improved problem-solving skills, learning, behavioral self-control, and emotion regulation through the growth of higher-order skills (called "executive functions") influenced by the prefrontal cortex.²⁸ These executive functions help to regulate memory, attention, and behavior, such as mentally holding and manipulating information in the mind, ignoring irrelevant information to focus attention on the relevant, and inhibiting an initial response in favor of a secondary response. In other words, as their brains develop and become more integrated, children become more proficient at using their memory, attention, behavior, and emotions in strategic, planful ways.



The integration of brain functions and interconnectivity in brain architecture have practical implications. For example, when stressful experiences activate specific neurobiological and hormonal systems within the brain, other systems, including those associated with learning and memory, may also be impaired.²⁹ Consequently, young children who experience chronic stress may have difficulties with learning in the classroom. The implication: fostering children's emotional well-being will help promote their cognitive development and mental achievement.

9. The young mind is astonishingly active, capable, and self-organizing.

The developing brain is not an empty vessel, passively waiting to be filled with knowledge, but rather an active organ that grows through its own

activity. The experiences that promote growth are those that provoke the brain's activity, often through the child's interest and engagement.

There are at least two implications of this principle. One is that *the experiences that are developmentally provocative will change as the brain matures*. Early in life, for example, an immature brain is influenced by general features of environmental stimulation (e.g., familiarity or exposure to language) but with greater maturity, more specific and detailed features of the environment become more important. If a young child is exposed to influences that are developmentally inappropriate or irrelevant (e.g., identifying letters to a baby) these influences will not have their beneficial effects. Likewise, if preschoolers are expected to exert greater self-control than their brains are capable, both children and adults

are likely to become frustrated. In other words, the environments that facilitate learning and growth will differ significantly for children of different ages. A high-quality learning environment for a fourth-grader is much different than a high-quality learning environment for a 4-year-old because of differences in brain development.

Another implication is that *interaction with appropriately responsive social partners is one of the most developmentally provocative experiences for the growing brain*. Regardless of the child's age, interaction with a sensitive adult offers much more than any commercial toy or DVD by providing stimulation that is active and responsive, calibrated to the child's readiness for new learning, individualized, multimodal, and very engaging.³⁰ There is as yet no mechanical substitute for lively interchanges with another human being.

10. Developmental neuroscience provides much greater insight into the hazards to avoid in brain development than opportunities for enrichment.

Developmental neuroscience has highlighted a broad variety of hazards to avoid to ensure healthy brain development. Many of these are associated with poverty, and most are preventable. As described earlier, these hazards include malnutrition of the mother during prenatal growth and of the child during the early years, inadequate health care, and exposure to dangerous chemicals, viruses, environmental toxins, and chronic stress during the prenatal and early childhood years. Prenatal alcohol exposure, early sensory deficits that

remain untreated (such as strabismic amblyopia, commonly known as “lazy eye”), accidents (especially those involving head injury), and extreme neglect or abuse also constitute hazards to healthy brain development.

By contrast, beyond recommending attention to health and responsive care, developmental neuroscience has much less to offer concerning strategies for improving the typical course of brain development. Many of the developmental processes discussed above unfold on a maturational timetable that is largely controlled by our genetics, and so it is not clear that interventions can indeed accelerate or improve the course of *typical* brain growth. In addition, the environmental experiences that have been identified to date as important for brain development (e.g., early exposure to

light and sound; hearing language) are hardly exotic interventions. Given that, it appears likely that other important environmental catalysts would be commonplace occurrences, and not linked to specially-designed toys or DVDs.

However, for children experiencing cognitive delays and difficulties in learning, developmental neuroscience offers some potential avenues for helpful intervention.³¹ Enlisting developmental neuroscience to create interventions to assist children at risk of academic delay is one of the more exciting areas of research in this field. For example, the *Tools of the Mind* curriculum is a promising brain-based program that helps young children develop executive function and self-regulatory skills.³²

Sensitive interactions with adults do more to promote brain development than any toy, CD, or DVD that purports to promote brain development. Government regulations should require and preschools should deliver services that enable adults to have rich interactions with children.





Interpreting Developmental Neuroscience

Any brain development findings should be interpreted against the rich backdrop of scientific understanding that already exists concerning children's *behavioral* growth and development. We should expect, in other words, that what we learn from studies of the developing brain will be consistent with what we already know about the growth of cognitive, social, emotional, and other behavioral capacities in children.

And indeed it is so.³³ Newborns crave novel stimulation and become bored with familiarity in a manner that is precisely what we would expect to see if the brain were significantly

expanding with new neural connections. Infants acquire proficiency in sensory and motor abilities before they acquire skill in language or in problem-solving skills, and those earlier skills equip them with essential competencies on which more advanced skills can be built. In addition, the growth of children's self-regulatory capacities—from sitting still at family gatherings, to playing “red light-green light,” to controlling emotional outbursts—is consistent with what developmental neuroscience concludes concerning the progressive maturation of the prefrontal cortex.

If we forget to connect brain

science with the science of behavior and development, we run the risk of moving too quickly to embrace services or programs that do not make sense for children.³⁴ For example, it is from a narrow focus on specific (sometimes poorly designed) studies that misleading conclusions concerning the influence of a Mozart sonata or an infant education curriculum on brain development can emerge.

Recommendations

- Healthy brain development begins with good maternal and child health and nutrition. Government and business should support prenatal and well-baby health care as well as prenatal and early childhood nutrition programs, sponsor public information efforts to reduce prenatal drug or alcohol exposure, and work to eliminate children's exposures to indoor and outdoor pollutants and toxins that can affect brain development. Preschool programs should make sure that they provide balanced, nutritious diets to children enrolled in their programs and that their environments are free from lead and other toxins.
- Because brain plasticity and flexibility declines throughout an individual's lifetime, early prevention is better and less expensive than later remediation. Health care agencies, early intervention programs, and preschools should ensure that they provide early hearing, vision, language, cognitive, and behavioral screenings, and that they link children to necessary services. Depending on children's needs, high-quality preschool environments may be able to provide the necessary remediation (especially with well-trained providers), but children with special needs should be linked as early as possible with Part C early intervention programs in their communities to make sure that they are offered the full range of services that might be helpful to them. In addition, if bilingualism is a goal, then early introduction of a second language during children's preschool years is beneficial.
- Sensitive interactions with an adult are better than any manufactured toy, CD, or DVD that purports to promote brain development. Paid family leave for new parents and family-friendly employer policies can help give parents the flexibility they need to spend time with their young children. Government regulations should require and preschools should deliver services that enable adults to have rich interactions with children. This means, for example, that every preschool classroom should have a high teacher-to-child ratio, small class sizes, and well-qualified and trained teachers who know how to best promote children's development. Public awareness campaigns and direct service programs to help parents understand the importance of rich, responsive social interaction for early brain development are also important.
- For most typically developing children, no special interventions beyond attention to health and responsive care are likely to be needed to promote brain development. Nonetheless, because experience affects brain development and because children's engagement helps determine how much they gain from their environments, preschools should embrace educational approaches that encourage child-oriented discovery, social interaction, language use, active learning, and appropriate self-regulatory expectations. In such approaches, children choose activities based on what captures their interests, rather than being driven solely by adult-directed curricula.
- Social-emotional and cognitive development are intertwined and preschool programs should recognize and focus on both, especially if they are concerned with school readiness. Instructional approaches should foster children's social-emotional and self-regulatory skills, which are essential for group learning and exercising the brain's developing capacities, just as much as they concentrate on early language or cognitive development.
- Exposure to chronic early stress is harmful, so community-based programs designed to address child abuse and neglect, domestic violence, and parental mental illness are important. Because preschool staff encounter families daily, they are often the first to notice when families are in crisis (usually because children act out or are unable to control their emotions in class). Preschool staff should therefore be trained and supported to identify children and families who are experiencing stress and to refer families to other community-based services as needed. Mental health consultation to preschool staff can help staff work with children who have been exposed to chronic stress and have developed behavioral problems.

Preschool programs should make sure that they provide balanced, nutritious diets to children enrolled in their programs and that their environments are free from lead and other toxins.



Conclusion

Understanding developmental neuroscience and its implications for parenting, practice, and policy remains a significant challenge more than 10 years after the I Am Your Child campaign brought early brain development to public attention. The unsettled professional opinion about this issue is reflected in a comparison of two articles. The first, published one year after the public engagement campaign, highlights the variety of educational implications of the emerging brain research and its importance to practitioners.³⁵ The other, appearing 10 years later, reports on an international conference of developmental scientists and educators who issued a declaration indicating, among other things, that “[n]euroscientific research, at this stage in its development, does not offer scientific guidelines for policy,

Preschools should embrace educational approaches that encourage child-oriented discovery over adult-directed instruction.

practice, or parenting.”³⁶ These discordant views reveal that at a time of remarkable new insights into the process of brain development, scientists are still debating the broader significance of this new knowledge. Still, program administrators, policymakers,

and today’s young children and families cannot wait until scientific knowledge is complete. This brief recommends the most reasonable steps based on the current state of our knowledge of early brain and behavioral development.



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