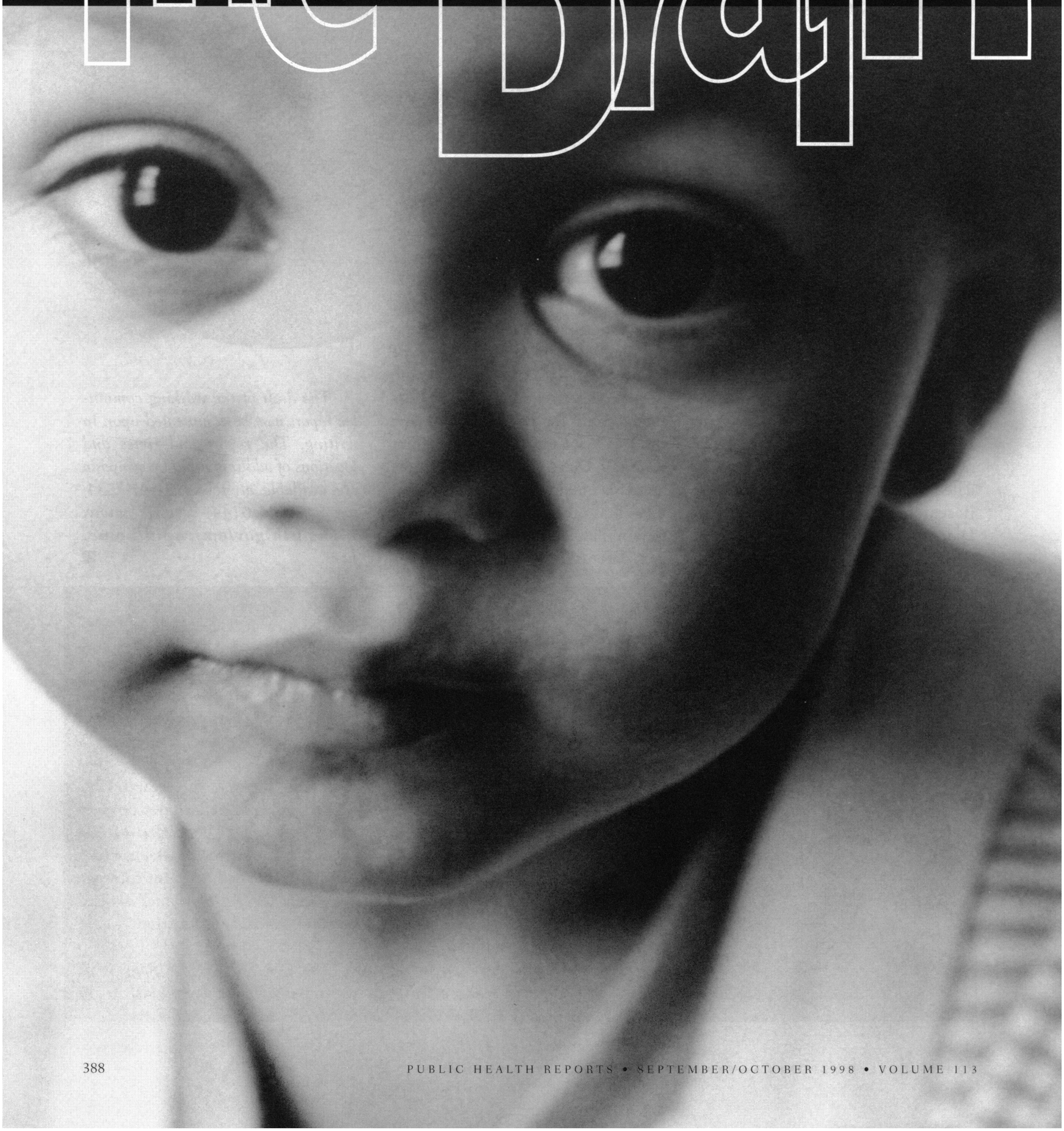
The Brain



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AND CHILD DEVELOPMENT:

Time for Some Critical Thinking

S Y N O P S I S

THERE IS WIDESPREAD interest in the claim that new breakthroughs in neuroscience have radical implications for early child care policy. Yet despite parents', educators', and policy makers' enthusiasm, there are good reasons to be skeptical. The neuroscience cited in the policy arguments is not new, depending primarily on three well-established neurobiological findings: rapid postnatal synapse formation, critical periods in development, and the effects of enriched rearing on brain connectivity in rats. Furthermore, this neuroscience is often oversimplified and misinterpreted. While child care advocates are enthusiastic about potential applications of brain science, for the most part neuroscientists are more cautious and skeptical. After reviewing the evidence and the arguments, the author suggests that in the interest of good science and sound policy, more of us might adopt a skeptical stance.

RECENTLY, A FLOOD OF POLICY REPORTS, conference proceedings, and professional and popular articles have proclaimed that "new" discoveries in brain science will revolutionize how we think about children, parenting, and early education. We have at our disposal, enthusiasts claim, a neuroscientific basis for an action and policy agenda on behalf of young children. Advocates of a brain science/child policy link cite evidence which they claim shows that certain early childhood experiences are necessary for optimal brain development.

This claim has support in high places—the White House, the National Governors' Association, private foundations, children's advocacy groups—and has immense popular appeal. However, there are also good reasons to temper our enthusiasm and to take a more critical, skeptical view of this claim. Among them is that the neuroscience advocates cite in support of their claim is hardly new; that the neuroscience is selective, oversimplified, and interpreted incorrectly; and that these claims and interpretations are emanating primarily from policy advocates, not from neuroscientists or even developmental psychologists. Indeed, to get from the brain science to the supposed policy implications requires some mighty leaps of faith and interpretation. These leaps are so long and perilous that we might do more for children by questioning than by accepting this popular claim.

THE BRAIN AND EARLY CHILDHOOD: THE BACKGROUND AND THE ARGUMENT

Interest in the brain is not new among educators and policy makers. Many of the same ideas about and discussions of how brain science might inform policy, practice, and parenting have been around for at least 30 years.[1-6]

Interest in brain and child development most recently surged in the early 1990s. In 1991, the Carnegie Corporation of New York formed its task force on the Needs of Young Children to address the "quiet crisis" afflicting children from birth through age 3. The task force's report, *Starting Points,* is justifiably hailed as the seminal document of the heightened interest in brain science and child development.[7] As stated in the report, the task force's mission "was to develop a report that would provide a framework of scientific knowledge and offer an action agenda to ensure the healthy development of children from before birth to age 3." The report pointed to the wide gap between scientific knowledge and social policy, a gap that is particularly wide—the report noted—between brain science and early childhood policy. Yet, *Starting Points* contained only a limited, superficial, and poorly documented discussion of brain research. For a foundation policy report, *Starting Points* received unprecedented, positive media coverage. Oddly, though, given the little brain science in the report (1½ pages out of 132), the media coverage emphasized what the new brain science meant for parenting, child care, and early education.

In February 1996, *Newsweek* helped bring the discussion of brain science and early childhood into the mainstream with its cover story, *Your Child's Brain.*[8] In June 1996, the Carnegie Corporation along with several other foundations sponsored a conference in Chicago, which served as the basis for the publication *Rethinking the Brain,*[9] released in conjunction with an April 1997 White House conference (titled the White House Conference on Early Childhood Development: What New Research on the Brain Tells Us about Our Youngest Children). The sponsors of the Chicago conference intended *Rethinking* to provide a more complete account than did *Starting Points* of the neuroscience that parents, educators, and Congress should use to reformulate policies and priorities.

The arguments made by the advocates of a brain science/child policy link rely on three relatively well-established findings from developmental neuroscience as a basis for their policy recommendations. First, neuroscientists have known since the late 1970s that in various species including rats, cats, and primates, there is a period of rapid synapse formation in the brain cortex. This period, during which connections rapidly form among nerve cells, starts prior to or shortly after birth, depending on the species.[10-14]

Second, neuroscientists have also known since the early 1970s that there are critical periods of experience-dependent development in some sensory and motor systems. The best-known example is that of critical periods in the development of the cat and monkey visual systems, as discovered by Torsten Wiesel and David Hubel.[15,16] Animals deprived of visual stimulation to one eye early in development remain permanently blind in that eye.

Third, studies have shown that at least in rats, complex or enriched environments increase brain size and weight as well as the number of synapses per cortical neuron. This work dates back to the 1960s. Beginning in the late 1970s, William Greenough and his colleagues have published some of the most rigorous and widely cited work in this area.[17]

None of this brain science, dating back as it does 20 to 30 years, could be accurately described as "new" in such a rapidly developing field. These three ideas, alone or in various combinations, appear in arguments to explain the importance of early childhood experiences and to encourage policies that assure children will have the experiences necessary for optimal brain development. These arguments, as they are popularly understood, can be distilled into a single sentence: In humans, the period of rapid synapse formation, which ends at around 3 years of age, is the critical period in brain development, during which enriched environments can have permanent and uniquely beneficial effects on children's brain development.

However, if we look critically at the neuroscience, the arguments, and the claims, we have good reason to be skeptical. The popular understanding of how brain science relates to early childhood is highly inaccurate and misleading. What follows is a brief description of the basic brain science and some examples of how it is used (and abused) to support specific claims about early child development.

EARLY SYNAPSE FORMATION

Building on work that began in the 1970s,[10,11] Pasko Rakic and Patricia Goldman-Rakic have studied synaptic development over the life span in rhesus monkeys.[12] Peter Huttenlocher and his colleagues have done similar, human neuroanatomical studies using autopsy material.[13,14] Although there are some unresolved differences between the monkey and human data, in both species synaptic densities—the number of synapses per unit volume of brain tissue—vary following an inverted-U pattern. At birth, synaptic densities in the human brain are approximately the same as those found in adults. In the months following birth, synapses form rapidly. In all areas of the brain, by age 3 years, synaptic densities peak at levels 50% higher than those found in adults. Synaptic densities remain at these elevated levels until puberty, when they decline to adult levels. Synaptic densities in adults are approximately the same as in newborns.

These neuroanatomical findings provide the basis for claims in the policy and popular literatures on early childhood about the unique importance of children's first three years. The first three years are important, the argument goes, because during those years, synapse production outpaces synapse elimination and the vast majority of synapses are produced.[9,18] The Education Commission of the States, a nationwide alliance for educational improvement affiliated with the National Governors' Conference, tells us that this time is developmentally crucial because "brain connections develop especially fast in the first three years of life in response to stimuli, such as someone talking to, singing to, reading to, or playing with the infant or toddler. Such experiences significantly influence brain development and enhance central nervous system connections that define the capacity to learn."[19] Brain development is so rapid during this period, advocates of the brain science/policy link claim, that by the time a child enters school at age 5, the most crucial learning years are past and he or she may have already irretrievably lost some crucial learning opportunities.[20] Rapid postnatal synapse formation is given as the reason why we should sing, talk, and read to babies, invest in high-quality early child care, and exploit this optimal learning period that augments intelligence and learning skills throughout life.

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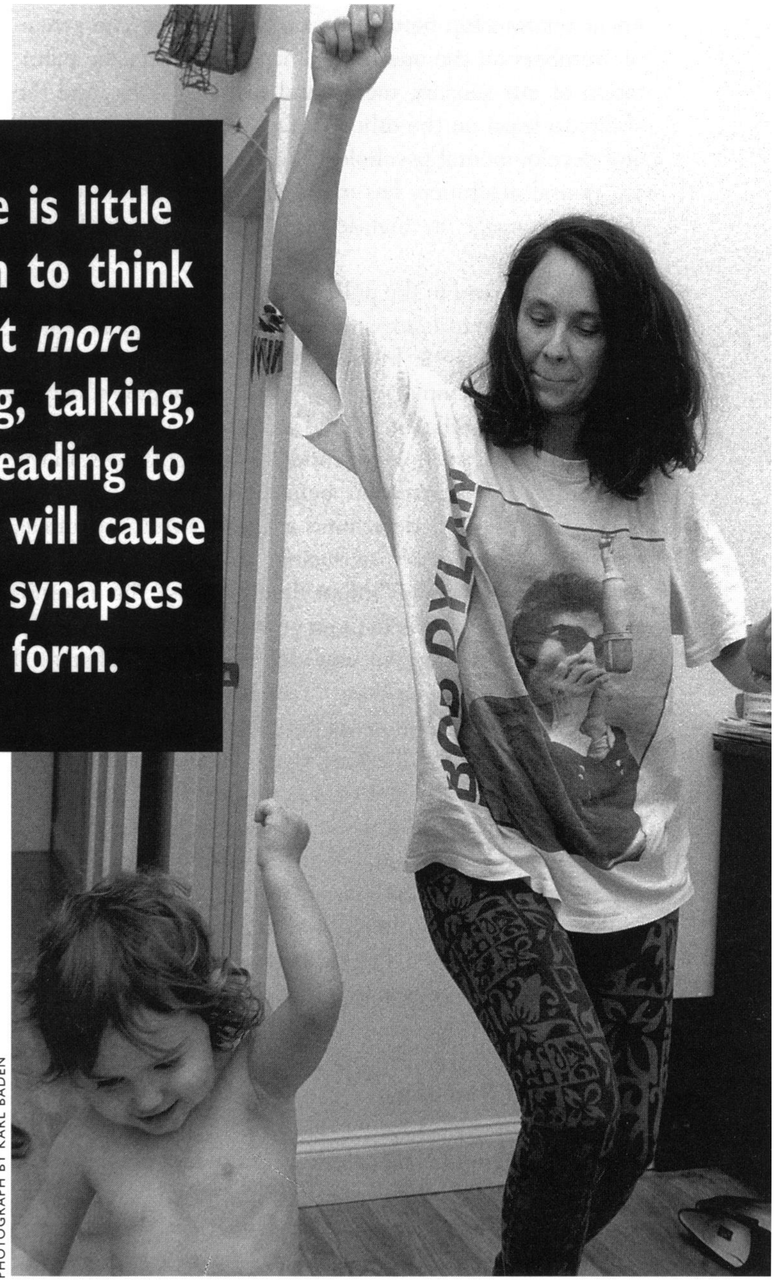

PHOTOGRAPH BY KARL BADEN

Although there may be excellent reasons to do all these things, what we know about early, rapid synapse formation does not by itself provide any justification for doing them. Although it is true that during these early years synapse formation outpaces synapse elimination, it is not accurate to say that during this period synapses form rapidly in response to environmental stimulation. Given what we know from animal studies, both deprivation and stimulation experiments, it appears that this process of exuberant synaptic growth is primarily under genetic, not environmental control. Monkeys raised in darkness, monkeys deprived of vision before birth, and monkeys delivered prematurely and visually overstimulated show the same pattern of rapid synapse formation as normal monkeys.[21] In monkeys, and no doubt in humans, experience after birth does affect brain development and neural circuitry, but it does so primarily by eliminating synapses formed during the period of rapid formation, not by causing them to form in the first place. Given what we know about what controls rapid synapse formation in animals including humans, there is little reason to think that *more* singing, talking, and reading to babies will cause *more* synapses to form.

We should also be skeptical of claims that the period of rapid synapse formation is the optimal time for learning and that when this period ends a child's most crucial learning years are over. If we look at the temporal relationships between the period of rapid synaptic proliferation and when sensory, motor, and memory skills emerge, it appears that the skills supported by a specific brain area first appear in rudimentary form when synaptic densities peak. However, these skills continue to improve during and after that time and continue to improve even as synaptic densities fall to final adult levels. For some short-term memory skills, we reach final adult levels of performance only at puberty, when synaptic densities fall to adult levels. At infancy and adulthood, synaptic densities are approximately the same, but our sensory, motor, and memory skills are obviously much more highly developed in early adulthood than in infancy. Thus there is no known simple, linear relationship between synaptic densities and synaptic numbers on the one hand, and intelligence, the maturation of our sensory, motor, and memory skills, and the ability to learn on the other. In fact, some neuroscientists and developmental psychologists argue that it is only after our neural machinery has matured at puberty that we are ready to engage in high-level learning and intellectual development.[12,21]

We often read in the policy and popular literatures that a child's ability to learn and function in society is largely determined by age 3. In fact, the entire discussion of the implications of brain science for child development occurs under the umbrella of this assumption. Although some developmental psychologists and child psychiatrists, in the attachment theory tradition, believe that childhood experiences before age 3 determine a child's future cognitive, emotional, and social well-being, there are others who question this notion of "infant determinism," the assumption that as the twig is bent so grows the tree. Those who question the assumption can also point to a substantial research corpus for support.[22] This is a complex issue that cannot be addressed in detail here. However, in evaluating the claims about the life-long significance of early experience on brain and cognitive development, readers should be aware that the claim is not universally accepted within the social and behavioral sciences. One sometimes gets the impression that early synapse formation figures centrally in the early childhood literature only because it happens to be a neural event that coincides with a developmental period some researchers deem important for other reasons.

CRITICAL PERIODS

The second neurobiological idea used to link brain science with early childhood policy is that of critical periods. Frequently cited is the example of Hubel and Wiesel's kitten's, which, deprived of visual input to one eye during the first months after birth, remained permanently blind in that eye. There is a tendency in the early childhood literature to identify "the critical period" in brain development with the period of rapid synapse formation in the brain, the first three years of life. Critical periods are a bit more complicated than that.

Appeals to critical periods are used to support claims about the life-long impact of early experiences and the permanent damage that can be done if critical periods are "missed." One use of this idea is to attempt to explain why the cognitive gains Head Start participants make are short-lived rather than long-lasting. The explanation is that Head Start begins for most children at 3 years of age, too late to fundamentally rewire the brain. Early child care experts have been quoted as saying that according to our "new" knowledge about infant brain development, Head Start may be too little, too late; to make a significant, lasting impact on children's development, enrichment programs are needed for children from birth to 3.[8,23] (We should note that there is a 20-year history of using whatever current brain theory is at hand to explain why Head Start is not all that its advocates might have hoped. For example, in the late 1970s, Herman Epstein's theory of growth spurts in the brain figured in such arguments.[3,24])

There certainly are critical periods in development. Some kinds of learning and skill acquisition are constrained within maturational windows. Common examples are newborn geese following the first moving object they encounter, male birds learning to sing, and the development of binocular vision in primates, including humans. For humans, we should also add aspects of social-emotional development and language acquisition. We must have the appropriate experiences at the right developmental moments to acquire certain social, language, sensory, and motor skills. One of Hubel and Wiesel's great contributions was to initiate a research program to identify the neural mechanisms underlying critical periods. They studied the visual system, as have many other neuroscientists since. Thus, we know much more about critical periods for vision than we do about those for other sensory and motor systems. Yet even for vision, neuroscientists are still not certain what causes critical periods to end.

Neuroscientists now understand that critical periods are not simply "windows" that slam shut. For human visual functions, such as visual acuity, critical periods appear to have at least three phases: a phase of rapid maturation of the function to near mature levels; a phase during which deprivation can result in degradation of the function; and a phase during which therapy or compensatory experiences can repair some damage due to deprivation.[25] Neuroscientists and clinicians also know that critical periods are complex in a second way. For any one sensory system, such as vision, there are different critical periods for specific functions—for example, visual acuity, stereopsis, binocular vision. When these periods occur and how long they last depend on when the specific brain areas supporting the function mature. For humans, critical periods for some visual functions extend well beyond age 3, until 8 or 9 years of age. For some aspects of language acquisition, critical periods appear to extend at least through puberty. Thus although some critical periods do occur before age 3, critical periods in humans do not in general map neatly onto the period of rapid synapse formation, that is, onto the first three years of life.

Claims about critical periods should also be assessed with a second caveat in mind. Although these claims often give the impression that there are critical periods for all kinds of learning, we have firm evidence for the existence of critical periods only for component functions within sensory and motor systems and, in humans, for components of language such as phonology and syntax. We do not know if critical periods exist for culturally transmitted knowledge, including reading, math, and music—often cited as examples. Reading and mathematics educators are generally skeptical that critical periods limit skill acquisition in these and other school subjects. For the present, we might best share their skepticism.

Some neuroscientists also argue that critical periods are limited to certain kinds of neural systems and functions. Some neural systems—vision is a good example—rely on environmental stimuli to prune synapses and fine-tune highly sensitive neural circuits. Environmental tuning allows us to have much more sensitive sensory systems than we could possibly have if the systems were hardwired at birth. Relying on the availability of specific kinds of environmental stimuli at just the right time would seem to be a highly risky way to develop the circuitry we need for survival. Of course, the risk diminishes to zero if the kinds of stimuli needed are overwhelmingly likely to occur in any even remotely normal environment. Over the course of evolutionary history, William Greenough argues, species have come to "expect" that the necessary stimuli will be present. Greenough talks about the "experience-expectant" plasticity of sensory and motor systems.[26] The expected experiences must be present at the appropriate developmental time, but the needed experiences are of a very

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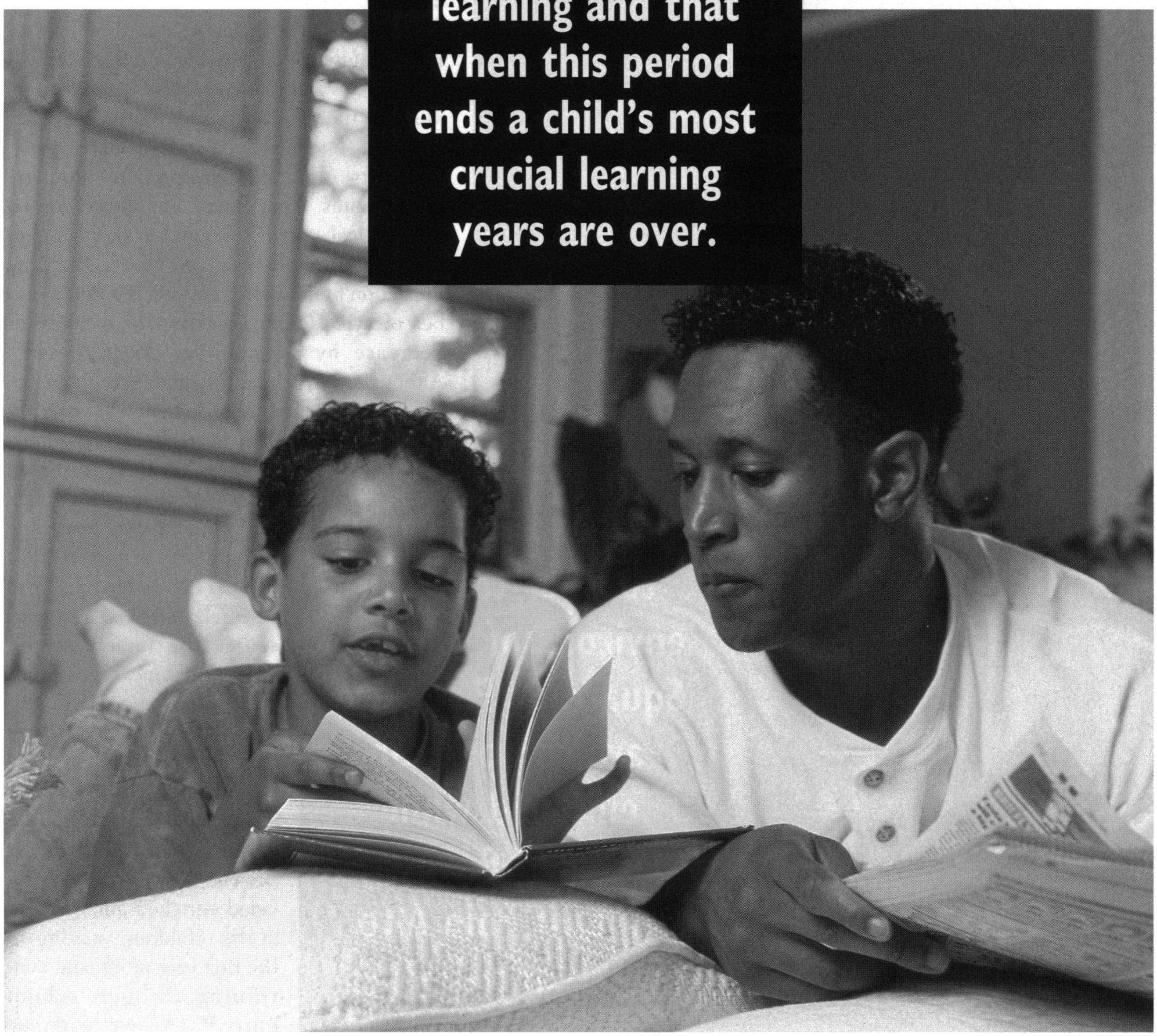

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general kind that are ubiquitous for the species—patterned visual input, the opportunity to move and manipulate objects, presence of speech sounds. Based on what we do know about critical periods from a neuroscience and evolutionary perspective, we can safely conclude that critical periods are unlikely to depend on highly specific experiences in highly specific social and cultural environments.

Children could be expected to acquire such skills, and they almost always do, in a range of environments—at home with a parent, with siblings or grandparents, with other child care providers, or in Head Start. Infants do not need highly specific, carefully tailored experiences for this kind of species-typical development to occur. For this reason, critical periods do not really speak to how we should design preschool or Head Start programs, choose toys, time music lessons, or establish early child care policies, with one important exception. Neuroscience and what we know about critical periods do tell us that it is extremely important to identify and treat sensory problems in children—for example, cataracts, eye misalignments, chronic ear infections—as early as possible. Normal, species-typical fine-tuning, even in a normal environment, cannot occur if the child cannot see, hear, or feel the ubiquitous environmental stimuli.

PHOTOGRAPH BY KARL BADEN

We have no reason to infer that the environs of Harvard Square or Palo Alto are complex or enriched while those of Roxbury or East Palo Alto are deprived.

Enriched or Complex Environments

Early childhood advocates claim that stimulation matters and that early stimulation matters most. In their view, research on the effects of enriched, or more accurately complex, environments on brain development supports these claims. They argue as follows: during the "critical period" of rapid synapse formation, "early experiences can have a dramatic impact on brain wiring, causing the final number of synapses in the brain to increase or decrease by as much as 25 percent."[27] Although, they admit, this finding is based primarily on rodent studies, people who care for children should take heart from the animal studies because "research bears out that an enriched environment can boost the number of synapses that children form."[9] This research, they claim, underscores the importance of early enrichment programs, especially for socially and economically disadvantaged children. An example commonly cited in the policy and popular literatures is the North Carolina Abecedarian Project, a program that provided enriched child care to at-risk children, starting in the first year of life and continuing through school entry.[28] (As we will see below, this project had a rigorous experimental design that has allowed long-term follow-up of participants.) Indeed, Colorado Governor Roy Romer recently told the *Rocky Mountain News*, "brain research showed that early childhood education could increase adult intelligence by a third."[29]

As much as we might want to believe Governor Romer, it takes several mighty leaps to get from rats to children to dramatic increases in adult intelligence, leaps that defy both logic and brain science.

Let's start with the rats. First, many neuroscientists who study how rearing environments affect brain development prefer the descriptor "complex" to "enriched." They see raising rats in groups in large cages filled with objects and obstacles as a laboratory simulation of the animals' normal, wild environment. It is enriched only with respect to lab rearing in single cages. In policy discussions, the term "complex" is also preferable. It prevents us, when we begin to think about how this research might relate to children, from too quickly defining enriched environments as culturally preferred ones. It reminds us that we should not identify complex rodent environments with human middle-class neighborhoods—we should be careful in leaping from rats negotiating obstacles to children learning chess or taking music lessons. We have no reason to infer that the environs of Harvard Square or Palo Alto are complex or enriched while those of Roxbury or East Palo Alto are deprived. Complex for rats does not readily translate into culturally enriched for humans.

Raising rats in complex environments does affect brain development. Neuroscientists have known since the 1960s that such rearing increases the size and weight of certain brain areas. More recent electron microscopic studies found that young rats raised in complex environments starting at 10-12 days of age had synapse-per-neuron ratios 20% to 25% higher than their littermates that were raised in isolation.[30] However, differences of this magnitude occur primarily in the visual area, not throughout the entire brain. This result is the source of the "25% more synapses in children" claim we see in the policy and popular articles.

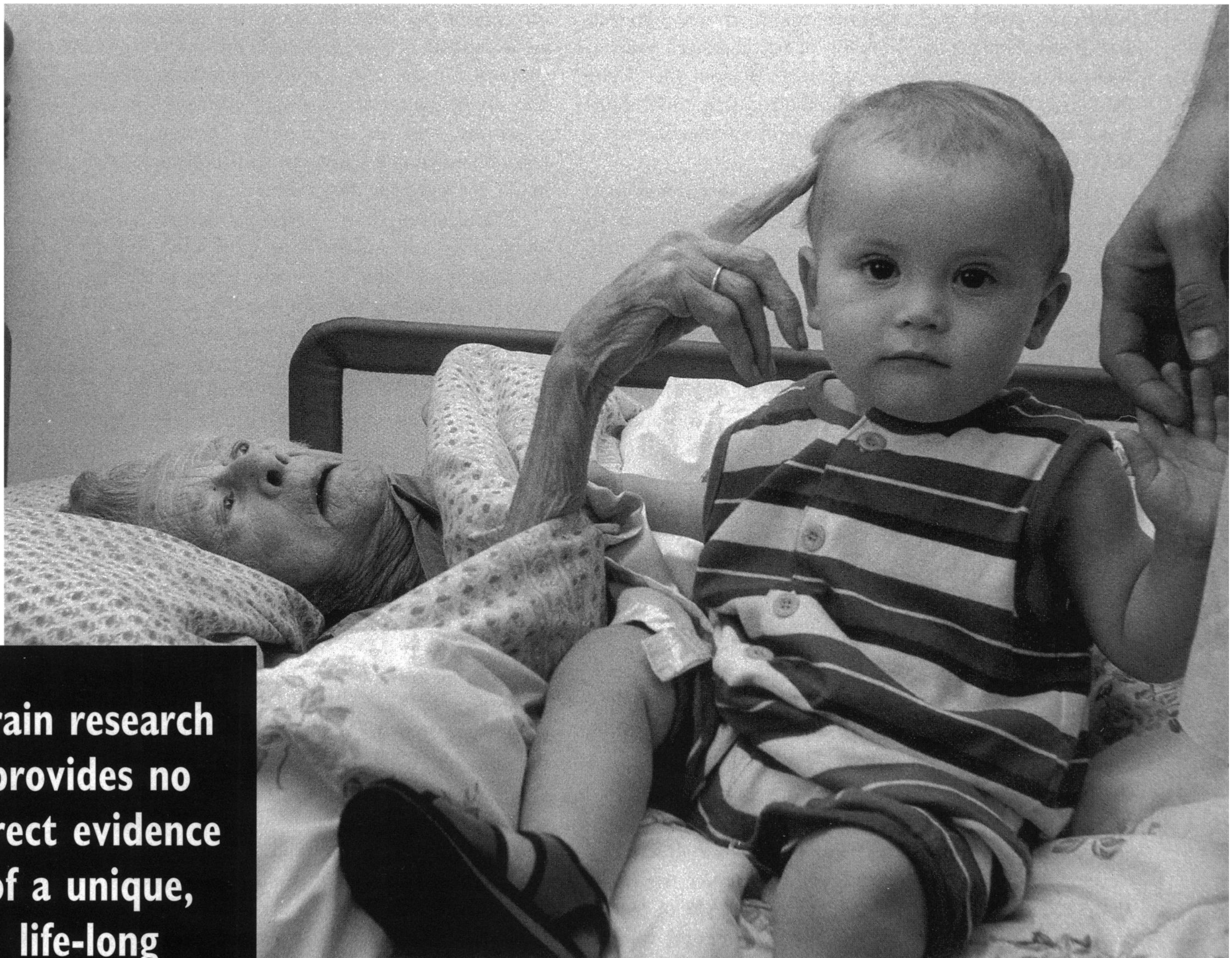
Neuroscientists have also known since the mid-1960s, although this is never mentioned in the policy and popular literatures, that complex environments have the same effects on brain structure (although to gradually lesser extents as animals age) throughout the animals' lifetimes. Research on complex environments does not point to the unique importance of early stimulation for this kind of brain plasticity. In fact, one of the most exciting discoveries of neuroscience in the past 30 years is that the adult brain remains highly plastic throughout the life span. Even in adulthood, changes in patterns of stimulation due to amputation or nerve damage, new experiences, or training and learning result in relatively rapid and substantial cortical reorganization.[31-34] This is what enables us to learn throughout our lives. In short, the research on complex environments is often distorted, misinterpreted, and oversimplified in the early childhood literature. Early stimulation might matter and it might even play an exceedingly important role in early child development, but the research on complex environments and adult brain plasticity does not provide the evidence.

Extrapolating from synapse-per-neuron ratios in rats to children requires another leap. Currently, we have no data to support a claim that early educational experiences increase synapse-per-neuron ratios by 20% to 25% in children's brains. The argument proceeds by assuming that what is good for the rats is good for the rugrats, suggesting that the effects of early intervention programs must have something to do with synaptic change. For example, it is easy to assume that measured changes on intelligence tests must result from some commensurate change in synapse-per-neuron ratios.

We should be concerned about children at risk for school and life failure. We should applaud and encourage longitudinal studies like that of the Abecedarian Project. But, as we move into policy, we should be clear about what the research does and does not say. The Abecedarian project is a fine example of behavioral science. In the follow-up studies done on Abecedarian participants at age 15 (7 to 10 years after the intervention ended), the participants did show improved school achievement that was related to the time and intensity of their participation.[28] However, the study design does not allow one to conclude that it was early intervention, as opposed to the duration of the intervention, that contributed to the improvements. The measured intelligence part of the story is less encouraging. Children in the study did show early gains in IQ, but they declined over the course of the follow-up. The largest gains in IQ appeared at age 36 months, with a 16.4-point differential between the intervention and control groups. But by age 15, children in the intervention group had IQs only 4.6 points higher than the children in the control group, a difference that would hardly be perceptible in classroom performance. (Here is where Governor Romer made his error; 4.6 IQ points represent an improvement of one-third of a standard deviation in IQ score, not a one-third increase in adult intelligence.) Furthermore, children in the intervention group had IQs in the low to mid-90s, still below the national mean of around 100. The effect of early intervention on measured intelligence is not as robust as many people had hoped and many still believe. Brain research provides no direct evidence of a unique, life-long impact of early childhood education.

Conclusion

The "new" brain science does not appear to offer much in terms of a scientific framework for an action agenda to



PHOTOGRAPH BY KARL BADEN

Brain research provides no direct evidence of a unique, life-long impact of early childhood education.

improve social policies for young children. When we see how advocates of a brain science/policy link misinterpret and oversimplify the science, we have reason to be skeptical, at least. Infants do undergo a period of rapid synapse formation, but it does not appear to be under environmental control. There are critical periods in development, but they operate to fine-tune our species-wide neural systems in an experience-expectant way. The stimuli required for this fine-tuning are available in any normal environment. "Complex" environments do, at least in rodents, affect brain connectivity, but they appear to do so throughout the lifetime of the animal. Attempts to extrapolate from rodent studies to the importance of early childhood intervention programs are logically, methodologically, and substantively dubious.

Policy makers and child care advocates are the most vocal in invoking brain science as a guide for policy. Generally, neuroscientists are more cautious. In 1992, Carla Shatz observed that although we know infants who suffer gross neglect develop abnormally, such observations do not support the view that enriched environments will enhance development or that extra stimulation is helpful. "Much research remains to be done," she wrote, "before anyone can conclusively determine the types of sensory input that encourage the formation of particular neural connections in newborns.[35] In a more recent review of the evidence, Charles Nelson and Floyd Bloom concluded that "it might be useful to question the simplistic view that the brain becomes unbendable and increasingly difficult to modify beyond the first years of life," noting that even at the end of adolescence, "the brain is far from set in its trajectory."[36] Similarly, William Greenough, whose work is widely cited by the brain science/child policy advocates, has stated that neuroscience does not support a selective focus of interest and resources on the first three years of life.

There are two positive outcomes of this intense interest in child development and the brain. First, the advocates have heightened interest in child development among parents, educators, and policy makers. Second, it has caused neuroscientists to reflect on what they do and do not know about brain development. Thoughtful brain scientists realize—and they are saying publicly—that they do not know nearly as much as the public and some policy makers claim they know. Reading the popular and policy literature on early brain development, they find themselves asking, "Do we really know that?" Their reflection promises to accelerate research in fields such as developmental cognitive neuroscience and neurobiology.

All of us interested in good science and sound science-based policy might be best advised to share the neuroscientists' caution and reflection. When we see in a policy document or popular article the assertion that "New research on the brain shows...," we should stop and ask ourselves, "Does it?"

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