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ABSTRACT

As part of a series of reports designed to support the implementation of Proposition 10: The California Children and Families Act and to provide comprehensive and authoritative information on critical issues concerning young children and families in California, this report reviews the research about early childhood brain development, examines the extent to which parents are aware of the importance of early childhood for brain development, identifies known risk and protective factors for cognitive and social-emotional development, and describes interventions that have been shown to support development in these areas. The report concludes by asserting that four findings emerging from neurobiology and psychology--that a child's brain is immature at birth, that it is changed by experience, that the timing of experience can be important, and that relationships influence a child's social and emotional functioning--have important implications for parenting and public policy. The report's two appendices graph the developmental course of human brain development and delineate risk factors and developmental outcomes. (Contains 93 references.) (KB)

UCLA Center for Healthier Children, Families and Communities

Building Community Systems for Young Children

Building Community Systems for Young Children is a series of reports designed to support the implementation of Proposition 10: The California Children and Families Act. Each installment is written by a team of experts and provides comprehensive and authoritative information on critical issues concerning young children and families in California.

August 2001

Brain Development in Early Childhood

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Brain Development in Early Childhood

I. Introduction

In recent years, parents and policymakers have become increasingly interested in the potential role of positive early childhood experiences in promoting a child' s emotional and intellectual well-being. Much of this interest has been sparked by numerous articles in the popular press claiming that recent advances in brain research can give parents guidance about everything from buying toys to choosing a preschool. While this growing interest in early childhood and the impact of early life experience is unquestionably a good thing, it has also contributed to the spread of sometimes inaccurate and frequently misunderstood information about what conclusions can be drawn from our knowledge of brain development. This report attempts to resolve many of the questions legislators, service providers and families have about the science of brain development, including if and how that science can inform the decisions they make for young children. To this end, the report:

- Reviews the research about early childhood brain development;
- Examines the extent to which parents are aware of the importance of early childhood for brain development;
- Identifies known risk and protective factors for cognitive and social/emotional development; and
- Describes interventions that have been shown to support development in these areas.

Like much of human development, the development of the human brain is the result of a complex interaction between nature and nurture, between the unique genetic code an individual inherits and his or her experiences both before and after birth.

The scientific community has called the years from 1990 to 2000 "the decade of the brain" because it was during this period, building on the work of the preceding two decades, that the scientific understanding of brain development increased exponentially. In this report, we have attempted to identify key scientific principles that have emerged from very intensive efforts to unravel the cellular and physiologic basis for brain development in humans. As is the case in any field of scientific study, even these basic principles are open to challenges by new information. For example, in the past 2 years, articles published in *Science* and the *Proceedings of the National Academy of Science* and described in the *New York Times* presented new findings suggesting that one piece of scientific orthodoxy – that individuals are born with all the brain cells they will ever have – may be incorrect (Gould et al., 1999; Blakeslee, 2000; Wade, 1999; Kolata, 1998). The articles describe a series of experiments demonstrating that parts of the monkey cortex responsible for memory formation and consolidation (the hippocampus) may grow new brain cells daily. Thus, while we have provided a summary of current knowledge about brain development, readers should keep in mind that because scientific investigation continually expands our understanding in new and sometimes unexpected directions, caution must be exercised in drawing conclusions for parents and public policy (Cicchetti and Cannon, 1999).

II. What is known about brain development?

Like much of human development, brain development is the result of a complex interaction between nature and nurture, between the unique genetic code an individual inherits and his or her experiences both before and after birth. Recent research in neurobiology and developmental psychology provides evidence of the specific processes involved in human brain development, particularly the process by which even the earliest experience affects brain development. However, much of what we know about human brain development is derived from studies that involve extensive and invasive experimentation on rats, monkeys and other animals. These experiments enable researchers to directly observe brain development by measuring and comparing physiologic processes directly from the brains of animals reared under various conditions.

Because it is not possible to directly measure the cellular processes involved in human brain development, scientists rely upon a number of reasonable assumptions about the extent to which animal and human brain development is similar. Since some animal and human psychological behaviors are similar, scientists can also make inferences about the neurobiological processes underlying these behaviors. Recent technological advances have improved the ability of neuroscientists to study human brain functioning directly through the use of non-invasive techniques such as electroencephalographic (EEG) recordings and functional magnetic resonance imaging (FMRI). These new technologies provide a non-invasive window on some of the physical processes that are observed in invasive animal studies. For example, a recent report in *The Lancet* medical journal presented information about how FMRI had been successfully used to observe the activation of the temporal cortex in fetuses who were played nursery rhymes through earphones placed on the mother' s abdomen, suggesting that the fetus' s brain is already processing information (Hykin et al., 1999). As more direct observation of brain functioning in humans is performed using such techniques, our understanding of the process by which human brains form is bound to increase significantly, and correlative research from other animals will be confirmed.

In the first three years of life, the number of synaptic connections in a young child's brain doubles to approximately 1,000 trillion, many more than will ultimately be present in the adult brain.

Four general findings have emerged from this growing body of knowledge that may have important implications for both parenting and public-policy efforts to support optimal brain development during early childhood.

1. A child' s brain is not mature at birth.
2. A child' s brain is changed by experience.
3. The timing of experiences can be important.
4. Relationships influence social and emotional functioning.

These four findings will be discussed and their implications considered.

1. A child' s brain is not mature at birth.

The newborn infant has approximately the same number of neurons, or brain cells, as an adult, yet only about 25% of his or her brain' s volume has developed (Blinkov and Glezer, 1968). Neither the connections between the infant' s neurons, nor the supporting cells that insulate them, are fully formed at birth. The infant's brain cells are connected by approximately 50 trillion synapses. By adulthood, synaptic density will increase as the number of synapses grows 10-fold by adulthood to approximately 500 trillion. Moreover, as these synapses grow and connections are established, each will be insulated by other cells called myelin. Together, these processes will cause brain volume to quadruple (Penn and Shatz, 1999).

In the first 3 years of life, the number of synaptic connections in a young child' s brain actually doubles to approximately 1,000 trillion, many more than will ultimately be present in the adult brain. These "extra" synaptic connections provide an important clue to how the brain is shaped by experience. Beginning at age 3 and continuing over the next decade or more, synapses are selectively eliminated; by age 15, the number of synapses has decreased by about half and remains relatively stable throughout the rest of the individual' s life (Huttenlocher, 1984).

Selective elimination of synapses is so essential to creating order in the human brain that some individuals with an overabundance of synapses may have serious behavioral or cognitive disorders. Similarly, studies of monkeys have indicated that cognitive ability reaches mature levels only after the selective elimination of synapses has been completed (Woo et al., 1997).

Most of the brain' s functional capacity does not develop until after birth, since the synapses connecting the neurons and the myelin insulating them have not yet fully formed. But nearly all of the neurons themselves develop prenatally, so that most of the scaffolding that synaptic connections will be built upon is in place at birth. If a developing fetus is exposed to malnutrition, viral infections, drugs, environmental toxins and other harmful substances (teratogens) that inhibit or alter nerve cell formation, this scaffolding may fail to develop normally and may result in negative outcomes such as schizophrenia, mental retardation, or more minor deficits, depending on when the exposure occurs (Shonkoff and Phillips, 2000).[1] In fact, a growing body of research suggests that the contribution a healthy pregnancy makes to optimal brain development might be comparable to that of appropriate interaction between parents and children once they are born, and therefore warrants greater attention on efforts to promote high-quality prenatal care and other public-health strategies to support and educate pregnant women (Thompson and Nelson, 2001).

A growing body of research suggests that the contribution a healthy pregnancy makes to optimal brain development might be comparable to that of appropriate interaction between parents and children once they are born.

1 The human brain demonstrates a remarkable capacity to recover as much as possible from various kinds of insults and injuries. This type of recovery is the result of the brain reassigning tasks from the part of the brain that is no longer capable of carrying out a particular function to another part of the brain by "rewiring" itself accordingly. The likelihood of a full recovery of functional capacity is constrained by the time at which the insult or injury occurs and the amount of appropriate compensatory stimulation available.

Because certain genetic problems can give rise to a variety of negative outcomes, it is also important to screen for birth defects and genetic problems prenatally and at birth so that appropriate intervention and treatment can be made available.

2. A child' s brain is changed by experience.

The structure and function of a child' s brain are influenced not only by its genetic inheritance but by experience. While genes program certain types of nerve cell connections, experience also programs and reprograms these connections. Depending on the type of function being programmed, the relative influence of genetic versus experiential influences can differ. For example, brain centers that control breathing and heart rate are relatively hardwired at birth, whereas higher cortical functions that have to do with learning and memory are sculpted and modified by experience. This new understanding of brain development yields a picture of the human brain as a plastic and self-organizing organ in which the development and maintenance of nerve connections are based on experiential demands and are not strictly predetermined (Gottlieb, Wahlsten and Lickliter, 1998).

In addition to fostering the growth of synapses between neurons, an individual's experiences determine which of the existing synapses will survive the process of selective elimination that begins around age 3.

Both the growth and elimination of synapses in the brain depend on an individual' s experiences. Experiences that stimulate activity in particular regions of the brain facilitate the growth of connections in those regions, so that synapses can be said to form in a "use-dependent" manner. Even before birth, the continual spontaneous firing of neurons in the immature brain is thought to stimulate synapse formation. For example, neurons that happen to be triggered at the same time will connect to each other, so that cells that "fire together, wire together" (Penn and Shatz, 1999). It has been suggested that the incidence of spontaneous neural activity supports a proportion of synapse formation and is genetically controlled; this would ensure that an adequate number of connections are formed during gestation and very early in life, before many external stimuli are available. While the connections that form from these spontaneous synaptic firings are not random, they are relatively disorganized.

The human brain is fundamentally an adaptive organ, whose physical organization is shaped by the environment. In this sense, learning is the process by which the brain responds adaptively to the environment in which a child is reared.

Nonetheless, even as these rudimentary connections are being made before birth, the brain is capable of learning. In one experiment done in Belfast, Northern Ireland, infants of mothers who had routinely watched a BBC soap opera during their pregnancy were found to respond specifically to the theme music of that show a few days after birth (Hepper, 1996). Following birth, the brain continues to create spontaneous neural activity, but, increasingly over time, synapse formation is supported by the external stimuli the infant receives from the surroundings, such as the taste of warm milk, the feeling of a mother's caress, or the sound of a father' s voice. The brain' s response to these external stimuli is known as "sensory-driven" neural activity. Synaptic firing, under the influence of these new, external stimuli, leads neurons to form connections to other cells that have also been activated by sensory stimuli and experiences in their new world. Because neurons that are activated by a particular type of stimulus most likely have a role to play in receiving, processing and responding to it, and because

cells that are activated at the same time become connected, sensory-driven neural activity drives the circuitry in a young child' s brain toward increasing organization.

As is the case in much of recent neurobiology research, animal experiments have revealed a great deal. For example, the amount or type of environmental stimulation has been found to have a measurable impact on the physical development of the rat brain. One now-classic study found that rats raised in enriched environments had 30% greater synaptic density in their cerebral cortexes than did rats confined to non-enriched environments (Black et al., 1990; see also Diamond, 1990). The rats in the enriched environment had access to challenging situations such as mazes, as well as a variety of visual stimuli. The researchers concluded that the observed difference in synaptic density between the two groups of rats reflected the difference in richness of experience, and that a more natural, stimulating environment allowed a rat' s brain to develop in a normal way.

In addition to fostering the growth of synapses, an individual' s experiences determine which of the existing synapses will survive selective elimination that begins around age 3. Again, the use-dependent principle applies: Experiences that utilize the connections in particular regions of the brain ensure that those connections will survive, while connections that are not utilized will be lost. Evidence for this phenomenon also comes from well-known animal studies. Kittens deprived of visual stimulation in one eye for a short time early in life permanently lost the ability to see out of that eye. In this study, and similar ones, neuroscientists concluded that the region of the brain responsible for visual perception was never encouraged to grow and maintain connections to that eye because the eye was not used (Hubel and Wiesel, 1971). For the same reason, children less than 18 months of age whose cataracts are untreated can have a dramatic and permanent loss of visual acuity in the untreated eye (Boothe, Dobson and Teller, 1985), and the duration of the time in which the eye is not used is directly related to potential visual acuity once the cataract is removed and vision is restored (Mitchell and Timney, 1984).

The fact that synapses grow and form connections on a use-dependent indicates that the human brain is fundamentally an adaptive organ, whose physical organization is shaped by the environment. In this sense, learning is the process by which the brain responds adaptively to the environment in which a child is reared. Therefore, learning includes much more than the verbal and cognitive skills that are the focus of K-12 classroom education.

While the human brain exhibits a remarkable capacity for "self-righting," severe deprivation can sometimes have permanent negative consequences for children.

It is also clear that extreme deprivation can have serious consequences for human brain development and functioning. A series of recent studies examined institutionalized Romanian children who had been deprived of appropriate social interaction early in life (Rutter, 1998; O' Connor et al., 2000). All exhibited signs of severe developmental impairment prior to their adoption into stable homes. Those who were adopted early — prior to 6 months of age — achieved nearly complete physical and cognitive catch up. While children adopted after 6 months of age did exhibit a significant catch-up, they nonetheless continued to have lower cognitive scores and general developmental impairment compared with the children adopted earlier. These studies suggest that while the human brain exhibits a

remarkable capacity for "self-righting" (DiPietro, 2000), severe deprivation can sometimes have permanent negative consequences for children.

Providing infants and young children with specific enriching experiences can boost their cognitive and behavioral functioning.

However, studies of extreme deprivation should not be interpreted to suggest that if parents provide their children with unusual types or excessive amounts of stimulation, their children' s brains will develop more quickly or have greater intellectual capacity. At present, there are no empirical data to suggest that providing extra stimulation above what is normally "expected" by the developing brain has a beneficial effect in terms of brain growth or synaptic connections. Instead, there are a number of studies by developmental psychologists that suggest that providing infants and young children with specific enriching experiences can boost their cognitive and behavioral functioning (Infant Health and Development Project, 1990; Ramey et al., 1992), though whether and how these observable differences in behavior are related to physical differences in brain structure is currently unknown.

3. The timing of experience can be important.

Early in life, different regions of the brain, each corresponding to a particular set of abilities or behaviors, become connected to the other regions at different times in a hierarchical fashion (Chugani, 1998). When a child is born, the brainstem — the "lowest" region of the brain responsible for basic functions such as heart rate and body temperature regulation — is immediately wired and stabilized because of its essential role in ensuring survival. Subsequently, other regions of the brain associated with a child' s developing emotional and sensory motor capacities begin to develop a web of selectively maintained synapses, driven by the interplay of genetic and environmental influences. Because the various regions develop, organize and become fully functional at different times, specific kinds of experiences facilitate development in each region during that region' s developmental period (Perry, 1997). These developmental periods for particular regions of the brain, and for particular abilities, range from short, well-defined "critical periods" to longer "sensitive periods" in which the onset of development in a particular area of the brain may be abrupt, its duration prolonged, and its offset usually gradual, potentially occurring over many years (Thompson and Nelson, 2001). Critical periods are the exception, not the rule, of brain development; sensitive periods are far more common.

Critical periods are the exception, not the rule, of brain development, and sensitive periods, in which the onset of development in a particular area of the brain is abrupt, its duration prolonged, and its offset gradual, potentially occurring over many years, are far more common.

During critical and sensitive periods, the brain appears to be relatively more plastic, and therefore both amenable and vulnerable to the influence of experience. At some point in time, existing synapses in a particular region of the brain are thought to stabilize, suggesting that it may become more difficult to create new connections in that region. Therefore, neuroscientists believe that the critical or sensitive period for each developing region of the brain represents a window of opportunity during which \specific experiences and stimuli are required in order to promote the use-dependent synaptic growth described above (Cynader and Frost, 1999). It is also during these windows of opportunity that interventions and other efforts to support brain

development are likely to have the greatest impact, suggesting that such efforts must be timed appropriately if they are to be effective and efficient.

Most of the studies documenting the existence and role of critical periods have focused on the development of sensory processing capacities (i.e., vision, hearing) in animals and on certain animal imprinting behaviors. But there is growing evidence for critical periods for other higher functions as well (Cynader and Frost, 1999; Cicchetti and Cannon, 1999). For example, newborn rats who were exposed to mild stress, such as being handled frequently by humans, showed significantly more controlled responses to stress as adults when compared to rats who were not handled early in life (Cynader and Frost, 1999). This suggests that there is a critical period for the development of effective neural control over the response to stress in rats, and that rats who do not experience mild stress during this time will not develop this important ability. Again, the implications of such animal research for human can only be inferred.

The development of language is one example of how sensitive periods influence brain development. The capacity to hear and produce all of the sounds, or phonemes, used in any human language is latent at birth. One study found that while both 1-month-old American and Japanese infants were able to distinguish between the English sounds of L and R, the Japanese infants could not make that distinction a mere 5 months later (Kuhl et al., 1997). Because the potential capacity to distinguish and produce specific phonemes that are not present in a child' s native language gradually decreases as the child ages, adult native Japanese speakers find it extremely difficult to distinguish between these unfamiliar sounds. Researchers have also identified a window between ages 2 and 14 for acquiring the sounds of a new language without an accent (Flege et al., 1995). However, it has also been shown that adult Japanese speakers *can* learn to distinguish between L and R if they participate in a program specifically designed to teach them the difference – in effect, reprogramming their neural connections through intensive, targeted experience (McClelland, 1999). Studies like these suggest that it is difficult, but not impossible, to acquire new language skills well into adulthood. For example, we all know from our own experience that it is possible to improve our vocabulary in our native language throughout our lives. Similarly, while it is unquestionably easier to learn to play a musical instrument during childhood, it is certainly possible for adults to learn to play with additional lessons and extra practice.

The brain plasticity that occurs during critical periods - enabling the development of abilities such as vision, hearing, and the capacity for language - has been called "experience-expectant," because it is responsive to stimuli that are so common in human life that they are practically guaranteed to be available.

The brain plasticity that occurs during critical periods — enabling the development of abilities such as vision, hearing, and the capacity for language — has been called "experience-expectant," because it is responsive to stimuli that are so common in human life that they are practically guaranteed to be available (Greenough et al., 1987). It is something of a relief that the development of sensorimotor skills seem to require only a minimum of experiences that nearly all young children will have (Di Pietro, 2000). Yet when health problems such as cataracts occur during the critical period for the development of vision, or when chronic ear infections occur during the critical period for the development of hearing, a child may fail to develop normal sensory abilities. The critical timing issues associated with experience-expectant development of the brain are one of the most important reasons that

children require early, prompt and timely access to health services when developmental problems are detected.

For other abilities — such as the ability to learn a new language, to improve our native language vocabulary, or to learn a musical instrument — the window of opportunity would be more accurately described as a sensitive period in that it appears to remain open for a longer period of time, if not throughout a person' s life. This type of brain plasticity has been called "experience-dependent." It is responsive to experiences that are not necessarily present in everyday life (Greenough et al., 1987), but that instead depend on an individual' s unique life circumstances. From an evolutionary standpoint, it is helpful for an individual to be able to acquire new abilities throughout life and to remain amenable to the influence of unexpected opportunities to learn more. Appendix A depicts brain development from conception through adolescence and suggests that while essential elements of brain development occur prenatally and during the first 3 years of life, brain development is in fact a lifelong process influenced primarily by experience-dependent, not experience-expectant, synapse formation.

From a policy standpoint, the goal is to ensure not only that all children develop functional sensory and motor skills, but that they are exposed to the experiences and social interactions that are thought to encourage the underlying experience-dependent neural foundation upon which literacy and other abilities can be built.

From a policy perspective, many of the most important brain-based capacities of children are not experience-expectant, but experience-dependent. For example, research suggests that literacy is a complex set of skills that can be encouraged by experiences that may not be available to everyone, such as being read to daily or being enrolled in early childhood education (Whitehurst and Lonigan, 1998). Thus, from a policy standpoint, the goal is to ensure not only that all children develop functional sensory and motor skills, but that they are exposed to the experiences and social interactions that are thought to encourage the underlying experience-dependent neural foundation upon which literacy and other abilities can be built. What constitutes optimal experiences for the development of cognitive, emotional or musical abilities has not yet been determined and is the subject of intense research. What is currently more well defined are the consequences of sub-optimal experiences and impoverished environments on brain development. Together, these two strands of research are, in effect, helping us to define the floor and ceiling of potential brain development.

Relationships are among the most important experiences that young children have, and they have a particularly strong influence on social and emotional functioning.

4. Relationships influence social and emotional functioning.

The research described above suggests how a child' s experiences early in life significantly affect the physical development of the human brain. At present, the connection between neurobiology and psychology – between the physical and the emotional – is still being defined. However, we do know that relationships are among the most important experiences that young children have, and that they have a particularly strong influence on social and emotional functioning. For example, one of the greatest predictors of social and emotional outcomes is a young child' s relationship with his or her primary caregiver (Sroufe, 1988). This relationship, known as an "attachment" relationship, develops when a child is between 6 and

18 months of age and reflects the sense of security the child feels in the presence of her caregiver (see Bowlby, 1969 and Ainsworth et al., 1978). Because feelings of safety and security in the caregiver' s presence elicit particular biological responses to stress, they provide a foundation for healthy social and emotional development, and can even positively affect the developing brain.

Children learn to regulate their emotional responses to individuals and events through their perception of their caregiver' s behavior (Fox, 1998). If the attachment relationship is secure, a child learns to rely on the caregiver to help regulate her response to stressful situations and, over time, begins to self-regulate. If the attachment relationship is not secure because of inappropriate, inconsistent or ineffective behavior on the part of the caregiver, the child can experience prolonged episodes of unregulated stress and, in extreme cases, fail to develop self-regulating abilities such as the ability to calm oneself down after being startled or the ability to put oneself to sleep. This prolonged exposure to stress hormones can even affect the synapses in the cortex, and can conceivably change the physical structure of the brain, if it occurs during the critical period of development for that specific brain region (Schore, 1996).

If the attachment relationship is not secure because of inappropriate, inconsistent or ineffective behavior on the part of the caregiver, the child can experience prolonged episodes of unregulated stress and, in extreme cases, fail to develop self-regulating abilities such as the ability to calm oneself down after being startled, or the ability to put oneself to sleep.

One group of parents whose children may be at risk for insecure attachment and prolonged exposure to stress is depressed mothers. Maternal depression occurs in a mild form in approximately 40% of all mothers and in a moderate or severe form in approximately 10% of mothers during the immediate postpartum period (O' Hara, 1995). Although exacerbated by the physiologic changes associated with childbirth, factors such as social support, family and spousal support, and employment play a critical role in a mother' s capacity to interact with her child. A mother who suffers from clinical depression has difficulty responding appropriately to her infants, is often "out of sync" with her developing child, and frequently fails to respond adaptively to the infant' s emotional signals.[2] Studies suggest that these mothers are either more intrusive and controlling, or less attentive and engaged than non-depressed mothers (Dawson, Hessl and Frey, 1994; Field et al., 1995). Observations of depressed mothers with their children can be quite dramatic: The infant smiles, the mother does not respond, and the child becomes agitated, looks away and appears distraught.

Children of depressed mothers tend to be more irritable and display sadness and anger more frequently.

The effect of maternal depression on children' s brains has also been measured in the laboratory. Electroencephalographic (EEG) — or brain wave — recordings demonstrate that children of depressed mothers show more activity in the frontal brain region when expressing negative emotions than do children of non-depressed mothers (Dawson, Hessl and Frey, 1994 and Dawson et al., 1997; Jones et al., 1997).

[2] There is growing evidence that maternal depression can negatively affect development during the prenatal period. This has been documented by neonatal assessment of behavior, EEG and stress hormone abnormalities soon after birth (Jones et al. 1997).

This pattern of increased activity indicates an attempt by the child to regulate her negative reaction to an event, but such attempts are often unsuccessful; children of depressed mothers tend to be more irritable and display sadness and anger more frequently.

What children need are interesting and stimulating experiences that can occur everyday, and that may or may not include high-tech extras.

Infants of depressed mothers have also been found to have higher and more persistently elevated levels of cortisol, a hormone whose levels are associated directly with stress, than do infants of non-depressed mothers (Field, 1988, and Dawson, Hessl and Frey, 1994). It is thought that this indicates that these infants perceive a lack of control over their environment and that, as a result, their ability to cope with stress is significantly impaired. Other studies suggest that persistently elevated levels of cortisol are associated with atrophy of the hippocampus, a region of the brain involved in memory and learning (Sapolsky, 1996). This would suggest that it is possible that maternal depression can have a permanent effect not only on the ability of the child to feel safe and in control, but even on the child' s ability to retain memories and therefore learn. More research about these sort of issues is necessary before firmer conclusions can be reached.

Although these maternal depression studies suggest that a vulnerability to the influence of relationships can sometimes lead to negative outcomes, cross-fostering animal studies suggest that positive relationships can actually protect against a genetic predisposition to behavioral deficits. For example, rhesus monkeys selectively bred to be highly reactive were raised by unusually nurturing foster mothers for 6 months. While their siblings who had been raised by their biological mother were less likely to explore their surroundings and exhibited exaggerated responses to minor changes in their environment, the fostered monkeys frequently left their mothers to explore their environment and exhibited less stress during weaning than even monkeys with a normal range of reactivity (Suomi, 1987). Moreover, once the fostered monkeys were permanently separated from their foster mothers and moved into larger social groups, they became especially adept at developing relationships with other monkeys and rose to and maintained top positions in their group' s dominance hierarchy (Suomi, 1991). Finally, once the female fostered monkeys became mothers themselves, they appear to have adapted the nurturing maternal style of their foster mothers despite their own original reactivity profile (Suomi and Levine, 1998).

Although there is no step-by-step guide to creating a secure attachment relationship between parents and children, most parents already know how to do this. However, factors such as depression, drug use and stress can reduce the ability of some parents to be consistently available and responsive to their children and to behave in a reliable and appropriate way.

Summary

So, what do the last three decades of brain research tell us about what constitutes an appropriate experience at any given point in a child' s life? On the one hand, research suggests that there are serious and potentially irreversible consequences when animals are deprived of the kinds of stimulation they would be expected to receive under normal conditions. On the other hand, we know that this kind of stimulation is readily available. Mother cats do not go to unusual lengths to provide their offspring with visual stimulation; rather, most kittens develop normal visual abilities from watching their

brothers and sisters wrestle, or from chasing a mouse. Similarly, most rats will develop normal brains from running through sewers or fields in search of food while learning to steer clear of predators. If we were to glean a lesson for early childhood brain development from these studies, it would be that what children need is not necessarily the latest high-tech mobile hanging above their cribs, or a classical music tape playing as they lie down for their afternoon nap. What they do need are interesting and stimulating experiences that can occur every day, and that may or may not include these high-tech extras. Such experiences include talking, playing, singing, looking at books – all the things that most parents can do with their young children, if they have sufficient time and either an intuitive or formal understanding of their importance. To the extent possible, children need these experiences to be provided in ways attuned to their emotional and other needs, and in accord with their developmental age.

Do studies of severe deprivation have implications for moderate or mild deprivation? We know that relationships are one of the most significant influences on a child' s developing brain and personality. Children learn a great deal from their caregivers, including how safe their world is. Caregivers who help children feel safe while exploring and discovering new things about their world are laying a strong foundation from which their children can grow up to be happy, confident adults. Conversely, caregivers who are consistently unable to comfort and reassure children during stressful situations are potentially laying the groundwork for behavior problems, learning problems and other serious problems, as indicated in longitudinal studies of insecurely attached children. Although there is no step-by-step guide to creating a secure attachment relationship between parents and children, most parents already know how to do this. Most parents consistently give their children a warm embrace when they are hurt or afraid, and because their children come to expect this response, they know whom to turn to when they fall down or encounter a frightening situation. However, factors such as depression, drug use and stress can reduce the ability of some parents to be consistently available and responsive to their children and to behave in a reliable and appropriate way. Only future research will reveal whether the behavior and learning problems associated with moderate or mild deprivation are associated with corresponding changes in the physical architecture of the brain, changes that might resemble the changes induced by severe deprivation. Future research will also need to determine if parenting capacity and responsiveness can be enhanced through interventions, and that "better parenting" result in better brains. Everything we know from animal studies suggests that we must be alert to this possibility.

III. What do parents know about brain development?

In one survey of California parents, 46% did not understand that the greatest amount of brain development occurs during the first 3 years of life.

Despite the importance of brain development to functioning throughout life, many parents do not know that the first three years of life are potentially the most critical. In a 1997 survey of California parents, 46% did not understand that the greatest amount of brain development occurs during this time. Fathers in particular (57%) were unaware of the importance of the first 3 years of life, and lower socio-economic status was also associated with less awareness of the importance of the first 3 years of life compared to later childhood years (Hochstein and Halfon, 1998). By 2000, these figures had improved significantly – 76% of parents said that the greatest amount of brain

development occurs in a child' s first three years – suggesting that public education efforts are working (CCHI, 2001). Nevertheless, these studies suggest that in order to assist parents in making choices that will support and optimize their child' s development, many parents still need to be made more aware of what is at stake in the first 3 years of their child' s life. Given the lack of awareness among fathers, it may be particularly valuable to independently address ways to involve fathers in interactions with infants and young children (Pruett, 1998). Fathers might also benefit from an improved understanding of how support for the mother of an infant or young child can enhance maternal functioning in the mother/child relationship, and thereby promote the infant' s or child' s well-being indirectly.

IV. What is known about the risk factors for brain development and functioning?

While brain-imaging techniques and other state-of-the-art monitoring technology give some sense of the functional and physiologic development of the brain, the specific nature of the relationship between the physical and the behavioral is not entirely clear. Nonetheless, we tend to think of observable behaviors, functional capacities and performance as proxy measures of brain development and functioning. Since we have seen that poor cognitive and social/emotional development can be related to physical and neuroendocrinological changes in the human brain, we might imagine that the development of psychopathology and early school failure are observable outcomes of suboptimal brain development and functioning. By examining the risk factors associated with these adverse outcomes, we can begin to understand the kinds of early childhood experiences that might hinder optimal brain development and functioning.

There is an emerging literature about the risk factors and protective factors for the development of psychopathology and school failure (see appendix B). Interestingly, this literature suggests that the risk factors for psychopathology and for school failure are often similar. These risks fall into five main categories: neurodevelopment risk, cognitive deficits and learning problems, early behaviors and relationships, family and parent characteristics, and parenting practices. The presence of more than one of these risk factors indicates a need for additional screening, assessment and intervention in order to prevent adverse outcomes. However, it should be noted that a single risk factor is not enough to result in psychopathology or school failure. Rather, it is the combined effect of multiple risk factors on a single child that presents a risk for negative social/emotional and cognitive outcomes. A study of the effect of socioeconomic status on child development found that children whose mothers were depressed *or* had low educational attainment *or* lacked social support were developing in a normal way. It was the children whose mothers were depressed *and* had low educational attainment *and* lacked social support who exhibited negative outcomes (Sameroff, 1998).

V. What is known about protective factors for cognitive and social/emotional development?

While researchers are beginning to identify the risk factors for the development of psychopathology and early school failure, and understand the pathways and mechanisms that lead to poor outcomes, the literature on specific protective factors and those factors that promote optimal development is more limited. In some cases, they are simply the absence of risk factors (i.e. high maternal educational attainment, two-parent families or high socioeconomic status). The protective factors discussed here involve family behaviors and activities parents can engage in to optimize their child' s cognitive and social/emotional development.

There are certain everyday experiences that can help a child achieve optimal cognitive development and acquire a healthy attitude towards learning. Children should be encouraged to explore their surroundings and be made to feel safe doing so. Children need assistance in learning the basic skills they will need during the transition to school and throughout their lives and have to engage in guided rehearsal and extension of each skill as they obtain it. Children should be rewarded for developmental advances and shielded from inappropriate disapproval, teasing or punishment. Finally, children need a rich and responsive language environment if they are to develop the early literacy skills that will prepare them for school.

Parents and other caregivers, including family members and professional child care workers, should strive to provide children with an environment conducive to these experiences. Wherever children spend their day, it is important that health, safety and good nutrition are a priority. Caregivers should focus on developing a warm, caring relationship with the children in their care and should know how to respond appropriately to cues and clues indicating the child' s needs. Caregivers should recognize that each child is unique and have appropriate expectations for each child. Finally, caregivers should talk, read, sing and play with children on a daily basis. Reading to children is an especially important activity that parents and other caregivers should engage in with children beginning at a very early age. Pediatricians also have an important role to play here by counseling parents about literacy development and distributing free books to families during well-child and other office visits.

Brazelton and Greenspan (2000) wrote that young children have 5 "irreducible" needs: ongoing, nurturing relationships; physical protection, safety and regulation; experiences tailored to individual differences; developmentally appropriate experiences; limit setting, structure and expectations; and stable communities and cultural continuity. Meeting these needs requires dedication, knowledge and time on the part of families and caregivers – a significant challenge given the competing demands of work and family, the low wages and inadequate training provided to the vast majority of child care workers, and the lack of social supports present in many communities. Thus, policymakers and the laws and programs they create have a significant role to play in empowering families to raise their children in a manner conducive to what we know about cognitive and social/emotional development.

VI. What is known about the relationship between the science of brain development and intervention programs for children and families?

Advances in developmental science have provided us with a great deal of evidence about the process of brain development. As previously discussed, research has shown that relationships with caregivers, the characteristics of the child' s environment, and a variety of specific biological influences can have a profound impact on brain development (Shonkoff and Meisels, 2000). Unfortunately, the link between developmental science and the development and impact of various interventions on children and families is not as strong as might be hoped (Guralnick, 2001). Evaluations of interventions — even those firmly grounded in developmental science — often show that they do not demonstrate strong impacts on development, or that because the apparent impacts have a long latency, they are not necessarily directly attributable to the intervention. As a result, there is still much to learn about the potential of specific types of interventions to support and promote healthy brain development and functioning, and child development in general.

Nonetheless, several recent research reviews present what is currently known about the impact of various interventions on child and family outcomes (National Research Council and Institute of Medicine, 2000; Karoly et al., 1998). The following discussion highlights a few programs that have been shown to have significant, positive effects on child cognitive and social/emotional development, educational achievement and health. These programs vary in many respects. Criteria for program participation ranges from low family socioeconomic status to low child birthweight. Some programs target children exclusively, while others include programs for parents. In-home services are a component of some programs, while others are center-based.

High/Scope Perry Preschool Project, 1962

This program, motivated by poor school performance among economically-disadvantaged children, targeted low-income and low-IQ children to improve short- and long-term cognitive and social outcomes. The program consisted of one or two years of center-based classes and teacher home visits for families with 3-year-olds. Follow-ups at ages 5-11, 14, 15, 19 and 27 showed that participants had higher IQ scores, improved academic achievement, lower welfare utilization and criminal activity, and higher employment rates than the control group (Karoly et al., 1998).

A cost-benefit analysis of this program revealed that by the time participants reached age 27, every $1 invested in the program yielded a savings of $7.16. The total savings to taxpayers was estimated to be $88,433 per child as a result of reduced need for special education services, reduced use of welfare, savings to the criminal justice system and potential crime victims, and higher taxes paid by participants upon entering the work force (Schweinhart, Barnes and Weikart, 1993).

Carolina Abecedarian Project, 1972

The goal of this program was to prevent mild mental retardation and improve competence at school entry among economically disadvantaged children. The program targeted high-risk week-old infants. Participants

were placed in high-quality educational day care for 5 years, and mothers participated in a 3-year program once their children entered school. Evaluations at ages 8, 12 and 15 revealed that compared to controls, participants scored higher on IQ tests (Karoly et. al., 1998).

A cost-benefit analysis of this program revealed that an investment of $10,000 per child per year yielded as much as $100,000 in savings, reflecting reduced spending on special education, welfare and juvenile crime (Campbell and Ramey, 1994).

Infant Health and Development Program, 1985

IHDP targeted premature and low-birthweight infants considered at risk for long-term intellectual difficulties and delayed development. This program was unique in its focus on biological risk and consisted of home visits, center-based day care and parent group meetings for a 3-year period. Evaluations at ages 3, 5 and 8 revealed higher IQ scores, higher receptive vocabulary test scores, and fewer maternally reported behavior problems among participants compared to controls. Effects were greater for higher-birthweight children. Maternal outcomes included better interactions with their children and longer periods of employment compared to mothers in the control group (Karoly et al., 1998. See also Infant Health and Development Project, 1990). A cost-benefit analysis of this program has not been completed.

Prenatal/Early Infancy Project, 1978

PEIP examined the effects of home visits on economically disadvantaged first-time mothers and their children from pregnancy through age 2. Participants were visited by registered nurses who were trained to educate parents, encourage friends and family to support mothers, and link families to other health and human services. This program was based on an ecological/systems model that was intended to take into account the total environment in which child development occurs. Evaluations at ages 3, 4 and 15 found that compared to the control group, participants engaged in more positive pregnancy behaviors, had fewer safety hazards and more development-promoting materials in their homes, and had fewer incidences of child abuse and neglect, and their children visited hospitals less frequently (Karoly et al., 1998).

A cost-benefit analysis of this program concluded that the initial investment of $3,173 was recovered with an additional dividend of $180 per family within 2 years after they completed the program. This savings reflects decreased spending on welfare and food stamps, increased tax revenues due to a higher labor-force participation rate, and a reduction in costs associated with child abuse and neglect (Olds, 1997).

Reach Out and Read

This program encourages pediatricians to provide literacy materials and services — including books, waiting room storytelling and parent education — to families with infants at well-child visits. A limited number of studies have suggested that this very low-tech intervention can be quite effective in helping parents promote early literacy. Several evaluations of the program have demonstrated that this intervention beginning at age 6 months increases parental literacy orientation and book sharing activities in the family, particularly for low income and Hispanic families (Needlman et al, 1991; High et al, 1998; Golova et al, 1999).

Healthy Steps

This program is an attempt to reengineer pediatric practice in order to enhance the long-term developmental outcomes of young children. Pediatric practices participating in Healthy Steps provide additional services such as extended well-child visits, home visits, educational materials for parents, telephone information lines, links to community resources and child development assessments. The effects of this program are currently being examined at 15 national and 9 affiliate evaluation sites (Guyer et al., 2000)

In addition to these programs, there are numerous public programs that have the effect of more generally supporting healthy development early in a child' s life. These include public health services such as nutritional services such as WIC, immunization services, child care subsidies and regulations, income and in-kind support, child support enforcement, and the Early Head Start and Healthy Start programs.

Novel Approaches

There are a number of other novel interventions that have recently been designed to support a child' s cognitive and social/emotional development. Some of these involve exposing young children to certain stimuli or experiences. For example, research suggests that interventions providing massage to infants of depressed mothers may serve as a protective factor, and that similar massage techniques may be beneficial for the depressed mothers themselves (Field, 1998). Other researchers have demonstrated that preschoolers provided with music lessons exhibit long-term enhancement of particular cognitive functions (Rauscher et al., 1997). These and other research findings are prompting some parents to play Mozart to their infants while they provide massage therapy. While these practices might potentially be helpful and enhance development, more definitive empirical studies are necessary to evaluate their impact. In the meantime, a cottage industry has bloomed in baby-stimulation products and toys all geared to enhance brain development. Again, most of these are untested. From a developmental perspective, any encouragement to parents to pay more attention to their children and their children' s responses is most likely a good thing. On the other hand, substantial public policy efforts should ideally be based on solid data and evidence so as not to risk wasting precious public dollars on programs and interventions that will have no measurable effect. Such efforts may ultimately result in widespread skepticism about the capacity of *any* programs and interventions to positively affect children's development, thereby lowering the likelihood of public support for programs that actually do benefit young children.

VII. Conclusion

The four findings that emerge from our growing understanding of neurobiology and psychology — that a child' s brain is immature at birth, that it is changed by experience, that the timing of that experience can be important, and that relationships influence a child' s social and emotional functioning — do have important implications for both parenting and public policy. They help to explain why early childhood is so important, and suggest how providing a child with a safe and stimulating environment in which to grow and develop can promote that child' s emotional well-being and cognitive success.

Although recent research has significantly advanced our understanding of human brain development, that understanding is still limited. Much more needs to be learned about how alterations in a young child' s environment affect the development of specific abilities and behaviors, and the relationship between neurobiology and psychology — between behavior and the brain — needs to be more fully understood. Although interest in the implications of brain research has increased dramatically in recent years, caution must be exercised when using conclusions from the still limited and changing body of empirical evidence to inform parenting practices or public policies. At this point, the science of brain development indicates that access to nurturing, supportive caregiving and a safe, stimulating environment does make a difference for child development, and that programs and policies that support families — especially those at risk for depression, poverty and substance abuse — can help parents promote optimal brain development and cognitive, social and emotional well-being in their children.

The implications of the brain research reviewed here are fairly straightforward:

- **The early years of life are no less important for the child' s physical, social and emotional development than the school years.**

Profoundly important forms of learning occur long before the child enters school, and these early learning experiences emerge from the earliest interactions between an infant and her caregivers, the emotional context of these early relationships, and the nature of the experiences. These early learning experiences do more than simply shape the cognitive content of knowledge: they shape emotional and self-regulatory behaviors, as well as the very architecture of the brain which will later seek and absorb knowledge in school. As we come to better understand the role of social and emotional experience on "emotional intelligence," we are also recognizing the imperative of this emotional scaffolding for cognitive development.

This improved understanding of the relationship between cognitive development and emotional development has resulted in a substantial change in the way we define "school readiness." In the past, the term referred exclusively to the presence of cognitive skills it was believed would alone enable young children to succeed in school. But school readiness is now being redefined to include measures of social and emotional capacities that are equally important predictors of academic achievement, in part because, like cognitive skills, they are an indication of healthy brain development. This new definition of school readiness suggests that a range of early childhood experiences, including but far from limited to cognitive skill development activities such as reading, are laying the groundwork for success in school and throughout life, and that kindergarten and first grade are too late to begin our communities' support for children and families.

Critics have argued that the excitement about early childhood may draw a disproportionate amount of resources to the first few years of life, causing policymakers to ignore the potential and need to support development in older children, adolescents and adults. The fact that the human brain has been found to exhibit plasticity and adaptability throughout life does suggest that no one time period is worthy of all of our resources but, rather, that those resources should be available for appropriate targeting during other sensitive periods across the life course. Presently, there are few educational, health and social service systems that are available to families with very young children, whereas there are substantial systems in place, including public elementary and secondary education, for older children, adolescents and adults. This suggests that investments in children are in fact out of synch with what we know about when and how brain development occurs. Proposition 10 and its emphasis on early childhood will inspire policymakers to correct this imbalance.

❖ **The first years of life may set the course for all future development.**

While neural and behavioral plasticity are present throughout life, the flexibility of the brain in the first years of life, and its adaptive capacity to grow and lay the groundwork for cognitive and emotional capacities in later life, is probably unmatched at any other time. It is quite possible that the developing human brain can be more efficiently and more profoundly supported and enriched in the first years of life than at any other stage. This possibility, still the subject of intensive research, is at the root of the current excitement about brain research. It is a possibility that is too important to be ignored by parents, policymakers and the community at large.

❖ **Early childhood is an investment opportunity for each family, each community, and for our society as a whole.**

Early childhood is an opportunity that offers families, communities and our society the chance to ensure that each child reaches his or her productive and creative potential. It also offers us the chance to ensure that no child experiences severe or even mild deprivation that may impair brain development and impose significant fiscal costs on school and health systems at a later date. To realize the human potential represented by infancy and early childhood, it will be increasingly important to understand the corresponding fiscal potential, and costs, associated with how we as a society address the needs of families with young children. It takes a well-functioning family, supported by a community, to grow a brain. This simple truth about infancy and early childhood means a great deal for public policy.

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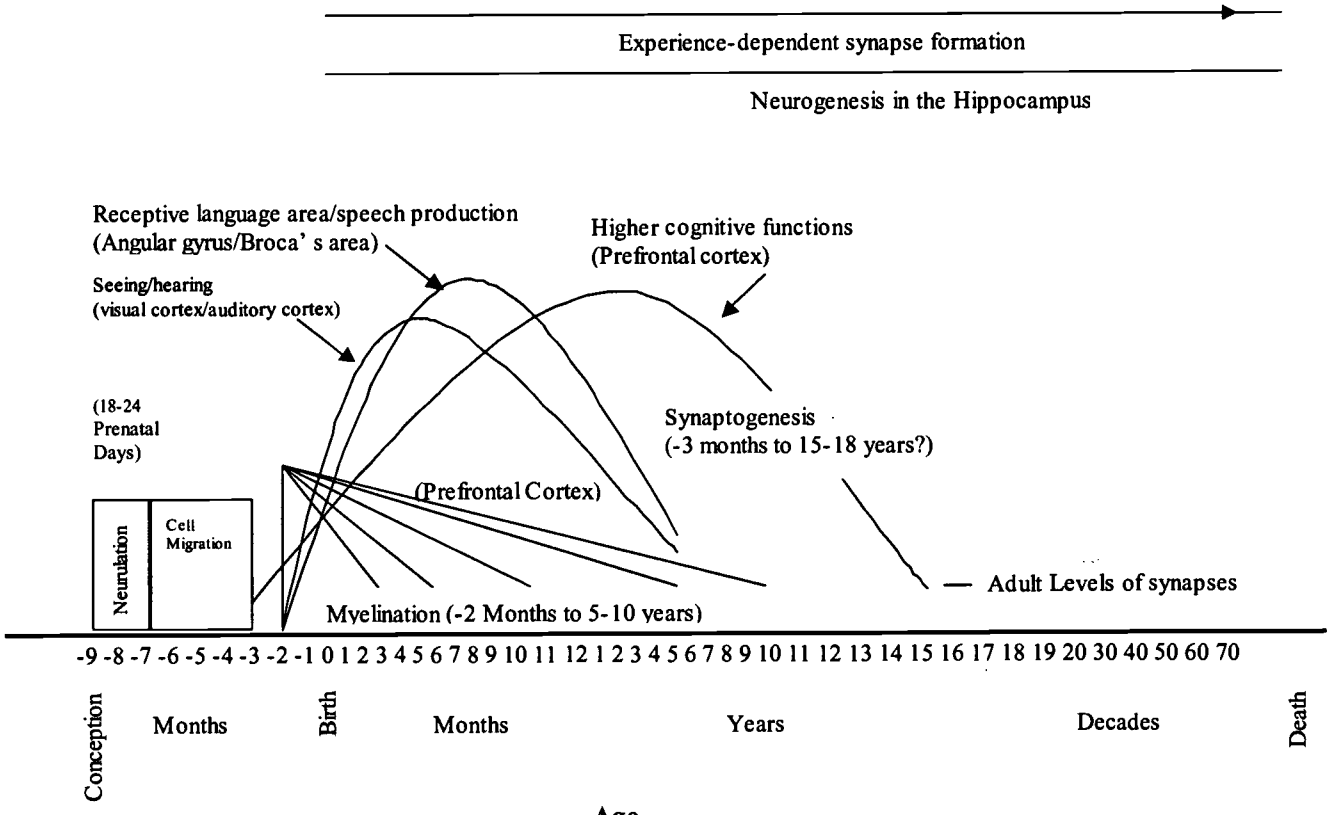
IX. Appendix A: The Developmental Course of Human Brain Development

Adapted from Thompson and Nelson, 2001



X. Appendix B: Risk Factors and Developmental Outcomes – A Summary of Recent Studies

Risk Factor	Social/Emotional Outcome	Cognitive Outcome
Neurodevelopment Risk		
Low Birthweight/Prematurity (McCormick et al., 1992; Hack et al., 1992)	Behavior problems	Learning disabilities, poor performance
Abnormal Neurodevelopment (Cadman et al., 1988; Bax & Whitmore, 1987)	Behavior problems	Learning difficulties
Abnormal Skull/Midface Development (Speltz et al., 1993)	Behavior problems	
Metabolic Abnormality (Den Ouden et al., 1996; Rochiccioli et al., 1992)	Motor coordination problems	Grade retention, lower IQ, school failure
Cognitive Deficits		
Low IQ/Poor Verbal Skills (Brier, 1995)	Delinquency, antisocial behavior	Lack of school success, negative attitude
Special Ed During Preschool (Fowler et al., 1991)		Difficult transition to elementary school
Early Behaviors/Relationships		
Difficult Temperament (Tremblay, Pihl, Vitaro & Dobkin, 1994; Hinshaw, 1992)	Antisocial behavior, delinquency	School failure
Hyperactivity/Externalizing Behavior (Campbell & Ewing, 1990; Campbell, Ewing, Breaux & Szumowski, 1986)		Difficulty adjusting to school
Insecure Attachment (Carlson, 1998; van Izjendoorn & van Vliet-Vissers, 1988)	Behavior problems, dissociation	Lower IQ
Family/Parent Characteristics		
Low Maternal Educational Attainment (Fowler & Cross, 1986)	Behavior problems	Early school failure
Divorce/Family Disruption (Guidubaldi & Perry, 1984)	Behavior problems	
Parental Substance Abuse (Streissguth, Barr, Sampson & Bookstein, 1994; Spohr, Willms & Steinhausen, 1994)		Delayed development, lower intelligence
Maternal Depression (Dawson, Hessl & Frey, 1994)	Behavior problems	Cognitive delays
Low Socioeconomic Status (SES) (McLoyd, 1998)	Behavior problems	Lower IQ, developmental delay
Immigrant Status (James, 1997)	Psychosocial problems, risk taking	School failure
Parenting Practices		
Coercive Discipline/Harsh Punishment (Brier, 1995)	Antisocial behavior	
Maltreatment (Eckenrode, Rowe, Laird & Braithwaite, 1995)	Lower perceived social acceptance	Lower IQ/test scores, grade repetition
Inconsistent/Erratic Limits & Routines (Brier, 1995)	Antisocial behavior	

Adapted from Huffman L and SL Mehlinger, Risk factors in the transition to school: a focus on behavioral and social outcomes during kindergarten and first grade. Presented to the Foundations and Agencies Funding Consortium on Child Development and Mental Health Issues, June 25, 1998.

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