



# Child maltreatment and the developing brain: A review of neuroscience perspectives <sup>☆</sup>

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## ABSTRACT

In this article we review neuroscience perspectives on child maltreatment to facilitate understanding of the rapid integration of neuroscience knowledge into the academic, clinical, and lay literature on this topic. Seminal articles from developmental psychology and psychiatry, a discussion of brain plasticity, and a summary of recent reviews of research on stress system dysregulation are presented with some attention to methodological issues. A common theme is that maltreatment during childhood is an experience that may affect the course of brain development, potentially leading to differences in brain anatomy and functioning with lifelong consequences for mental health. The design of prevention and intervention strategies for child maltreatment may benefit from considering neuroscience perspectives along with those of other disciplines.

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## 1. Introduction

There were nearly 800,000 verified cases of child maltreatment in 2007 in the United States alone, in addition to reported cases that were not verified and incidents that were simply not reported. Sixty percent of those children suffered from neglect, 10% were physically abused, and almost 2000 children died, most of them younger than 4 years of age (U. S. Department of Health and Human Services, Administration on Children, Youth, and Families, 2009). These statistics represent the experiences of individual children who have

suffered nonaccidental physical and emotional injuries, primarily from caregivers, including broken bones, black eyes, ruptured eardrums, tearing around the genital area, inadequate nutrition, clothing, and medical care, and constant derogation and ostracism (Scannapieco & Connell-Carrick, 2005). The costs to individuals and society in terms of pain and suffering, compromised quality of life, physical and mental health problems, medical expenses and reduced productivity, and programs to combat this social problem are enormous (Cicchetti, 2007).

Despite decades of research, there is little consensus about how to prevent maltreatment, provide intervention for victims, and ameliorate its possibly lifelong developmental consequences (Feerick & Snow, 2006; Webb, 2006). Moreover, a reliable and valid system for defining, measuring, and classifying types of maltreatment has not yet been developed (e.g., Feerick, Knutson, Trickett, & Flanzer, 2006; Gershater-Molko, Lutzker, & Sherman, 2003), which makes it difficult

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to interpret and generalize the results of research. Clearly, much needs to be done on all fronts to combat child maltreatment, which shows no signs of abating in our modern society.

Although knowledge from neuroscience disciplines has only recently begun to be integrated into this complex multidisciplinary endeavor, its influence is already widespread. This rapid growth of interest has been spurred, in part, by the development and use of brain imaging technologies (e.g., Giedd, Shaw, Wallace, Gogtay, & Lenroot, 2006; Puce, 2005), and by a large body of research that describes the ways in which the brain changes with experience throughout the lifespan (e.g., Greenough, Black, & Wallace, 1987). It is believed that the integration of neuroscience research will help uncover the mechanisms by which maltreatment during childhood puts individuals at risk for physical and mental health problems as well as educational and social difficulties. The ultimate hope is that such information will contribute to the design of more effective prevention and intervention strategies as well as social policies pertaining to the support of families in raising their children.

## 2. Overview and purpose

The purpose of this article is to review neuroscience perspectives on child maltreatment for professionals who are not experts in neuroscience. Basic literature, about which professionals in the treatment and prevention of child maltreatment should be familiar, is described. This article may thus be used as a metric of sorts for understanding the integration and discussion of neuroscience that is now common in articles, chapters, and books on child maltreatment, regardless of whether they are written for an academic, clinical, or lay audience. Several examples illustrate the scope of such integration.

Houshyar and Kaufman (2005) argued that a framework based on the concept of “resiliency” can be useful in guiding maltreatment research because it focuses on the processes by which some children develop into well-adjusted adults despite their adverse circumstances, and identifies some of the protective factors, such as supportive caregivers, that assist them in doing so. They reviewed the preclinical (animal) and clinical research on the neurobiological effects of early stress and some factors that mitigate adverse outcomes to support their argument. In contrast, Stien and Kendall (2004) wrote to mental health professionals from a clinical perspective about a psychiatric treatment approach for childhood post traumatic stress disorder (PTSD), a possible result of child maltreatment. It is based on “the new neurobiology”, the weaving together of developmental neuroscience research on the biological aspects of attachment theory with traumatology, the study of the effects of childhood trauma on the structure and function of the brain. One treatment objective is to attempt to reverse some of the brain impairments that may have resulted from chronic stress by providing positive experiences. Thus, in addition to psychological and family treatment goals, there are psychobiological goals such as decreasing stress reactivity and modifying brain connections through new experiences.

Two examples characterize the effort to communicate the link between child maltreatment and brain functioning to a larger audience. Grayson (2006) published a review of the effects of abuse, neglect, and trauma on children’s brain development and functioning and described the implications of this knowledge for child protective services caseworkers. The review is preceded by a brief description of brain structure, organization, and development so that the links between a neuroscience perspective and maltreatment can be understood and appreciated. Perry and Szalavitz (2006) targeted a more general audience with a recent book of case studies from their clinical work at the Child Trauma Academy. These children had experienced abuse and neglect, or had witnessed family violence. The way in which maltreatment may change brain function and what that knowledge can contribute to therapy forms a consistent thread throughout this very personal narrative. One notable chapter is a

report of Perry’s involvement with the children who were released from the Branch Davidian compound in Waco, Texas during the government raid. His experiences with these children, who had lived in constant fear of physical punishment, food deprivation, isolation, and sexual abuse, led him to conclude that the most powerful therapeutic experiences can occur in the context of naturally occurring relationships.

The broad field of child maltreatment is similar to disciplines, such as developmental psychology, psychiatry, social work, public health, and education, which are rapidly integrating the results of neuroscience research into previously acquired knowledge (e.g., Byrnes, 2001; Folensbee, 2007; Kandel, 1998; Lombroso & Pruett, 2004; Segalowitz & Schmidt, 2003). Brain plasticity, one facet of which is the ability of the brain to respond to experience by modifying its structure and function, both during development and throughout life, is the major concept guiding this integration. Maltreatment during childhood is viewed as experience that contributes to brain development, potentially leading to differences in brain anatomy and functioning. A recent study illustrates a typical methodology used to investigate the link between maltreatment and brain anatomy and some of the difficulties with interpreting the findings.

Using magnetic resonance imaging (MRI), Teicher et al. (2004) found that a group of pre-adolescent children who were admitted for psychiatric evaluation with histories of neglect or physical, sexual, or psychological abuse, had significant reductions in specific areas of the corpus callosum compared with a contrast group of children who were admitted for psychiatric evaluation without such histories, and a control group of healthy children (The corpus callosum is a tract of nerve fibers that connects the left and right hemispheres of the cortex so that unified perceptions and memories can result from the somewhat different functions performed by each side of the brain [Carlson, 2004]). Regression analyses indicated that the experience of neglect was most consistently associated with size differences in four different regions of the corpus callosum. Gender differences were found, with neglect being more important for boys and sexual abuse more important for girls in terms of these differences. The authors discussed their findings by relating them to experimental studies with rats and primates that have produced similar results and concluded that more attention should be paid to child neglect because of its prevalence and because such experience may affect brain development more severely than previously thought.

This well-designed study illustrates some of the difficulties involved with conducting research on this topic. One problem is that precise information about the environments and experiences of the children was unavailable; children were placed in maltreatment categories from a retrospective review of inpatient records. Furthermore, most children were judged to have experienced more than one type of neglect and abuse, making it impossible to directly compare brain development associated with neglect alone with that of independent groups of children who had experienced other types of maltreatment. A strength of this study, however, is that it was conducted with children and such studies are not plentiful. Retrospective studies of adults who were abused as children are far more common (e.g., Nemeroff, 2004), and suffer from a variety of problems that make it impossible to determine if the abuse was the likely cause of the differences in brain anatomy or functioning. Teicher, Tomoda, and Anderson (2006) argued that experimental research using animal models is necessary to eliminate competing explanations for the brain differences. For example, it could be argued that atypical brain anatomy and functioning lead to abuse.

Even when maltreatment experiences seem similar, however, children will respond differently to them for both genetic and environmental reasons. The importance of genes in influencing children’s response to maltreatment was well-illustrated by Caspi et al. (2002) who analyzed data collected as part of a longitudinal study conducted in New Zealand. Boys who were maltreated were

more likely to develop conduct disorders and become violent offenders if they were genetically susceptible, that is, if they possessed the gene variant that resulted in low amounts of an enzyme that helps to inactivate neurotransmitters, the substances by which neurons communicate with one another. Higher amounts of this enzyme help the nervous system cope with the increased stress of maltreatment. Additional studies have replicated this effect and indicate that susceptibility to depression in maltreated children is also moderated by genotype (e.g., Kaufman, 2008).

There are numerous difficulties with conducting and interpreting neuroscience research connected with maltreatment and applying the results to the complexity of children's and families' lives. In addition, because considerable neuroscience research is relevant to child maltreatment and is being integrated with an even greater body of existing work from psychology, psychiatry, child development, social work, and other social sciences, the sheer amount of information is daunting. Consider that one recent 6½ page review of a subset of this research contained 193 citations (Teicher et al., 2003). Thus, the purpose of the present article is not to provide a comprehensive review of the literature, but to describe and illustrate the various perspectives that are part of this ongoing integration, note some additional areas that are less frequently discussed, and comment on some of the possible implications for prevention and intervention with child maltreatment.

We will first describe several seminal publications from the 1990s that appear to have set the stage for current research. The next section will provide an overview of the effects of experience on the brain during development and throughout the lifespan; this is the common basis for the integration of maltreatment and neuroscience. The third section will focus on several recent reviews that describe the dysregulation of the stress system as a mechanism that links the experience of maltreatment with the risk for atypical brain development and some types of psychiatric disorders including PTSD. In the final section we will speculate about the contributions of neuroscience perspectives for understanding child maltreatment and developing more effective prevention and intervention strategies.

One barrier to understanding the neuroscience of child maltreatment is the highly technical nature of original research reports and review summaries. These require some knowledge of brain anatomy, functioning, and development, as well as neuroscience methods and genetics. Throughout this review we will provide definitions and explanations of essential concepts as they appear for readers who do not have this background. Accessible introductions to brain anatomy, functioning, and development can be found in Drubach (2000), Linden (2007), Marcus, 2003, and Thompson (2000). Puce (2005) provides a short overview of the technologies being used to study the structure and functioning of the human brain. The Society for Neuroscience website ([www.Sfn.org](http://www.Sfn.org)) provides neuroscience perspectives on hundreds of topics related to typical and atypical human functioning. For guidelines on how to organize the task of exploring the neuroscience literature pertaining to one's areas of professional interest, see Twardosz (2007).

### 3. Seminal neuroscience perspectives on child maltreatment

The first attempt at a comprehensive review of neuroscience research pertinent to child maltreatment probably appeared in 2000 (Glaser, 2000); however, two 1995 publications are notable for setting the stage for such integrative work. Cicchetti and Lynch (1995) drew the results of neuroscience research and the work of numerous developmental scholars into a systems framework for understanding the atypical development that appeared to result from maltreatment, and for generating hypotheses about trauma-induced changes in brain development that promote atypical behavior. They began from the premise that gross departures from the species-expectable environment will produce deviant outcomes through processes that

involve the continuing interaction between the individual and multiple aspects of the environment such as the family, peers, social institutions, and culture. The "species-expectable environment", a well-established concept in developmental psychology, refers to the range of conditions that support typical human development, including protection and nurturance from adults, and opportunities to explore and learn from the environment. Child maltreatment creates an environment that is outside the normal range for the human species; it will lead to deviant outcomes because it is not well-matched to the human genotype. Severe neglect, for example, has been related to linguistic delays, fewer social language exchanges, and less direct verbal teaching by parents (e.g., Allen & Oliver, 1982; Culp, Watkins, & Lawrence, 1991). (See Cicchetti & Valentino, 2006 for a review of the relationship of child maltreatment to language, play, and representational thought.)

Cicchetti and Lynch's work represents a developmental psychopathology approach to the study of child maltreatment, the striving to understand typical human functioning by studying pathology and vice versa (Cicchetti, 1989). In keeping with a systems approach, they discussed incidence, etiology, societal organization, family dynamics, parenting styles, intergenerational transmission of maltreatment, and its numerous consequences for children's development. The neuroscience information focused primarily on how the caregiving experienced by an infant helps to organize neurobiological systems related to regulating stress and affect regulation. Maltreating parents, who themselves may have difficulty coping with stress, may be unable to provide the sensitive and responsive care that promotes the infant's ability to modulate strong affective states; the experience of such care may help to organize the neurobiological systems involved in stress regulation in ways that lead to impaired ability to cope with stress in the future. Moreover, disruptions in attachment may also lead to disruptions in the endogenous opiate system, related to the ability to be comforted, and in the future ability to parent. Cicchetti and Valentino (2006) continued this integration with a more elaborated ecological-transactional model of child maltreatment that focused on resilience and the brain as a dynamic, self-organizing system.

In contrast to these broad-based developmental systems reviews, Perry, Pollard, Blakley, Baker, and Vigilante (1995) took a psychiatric perspective on the way children's brains may adapt to trauma, including physical and sexual abuse, resulting in a brain that promotes atypical ways of responding. The authors clearly stated that their views were preliminary and intended as a guide for future studies. They were based on extensive clinical experience with infants and children who had experienced trauma as well as the emerging understanding of adult PTSD, and described how the experience of trauma "...can transform a child's world into a terror-filled, confusing miasma that so dramatically alters the child's trajectory into and throughout adult life" (p. 273).

The authors' premise is that the human brain, composed of neurons that change in response to signals from the outside environment, responds to the experience of a traumatic event. That response is different depending upon whether the individual is an adult or child. The mature brain can be sensitized by a traumatic experience, such that a similar response can be produced by less intense stimuli in the future. However, a traumatic event and the resulting brain sensitization in a child has a much more profound effect because the immature brain is organizing itself and is dependent upon information from the environment to do so. Different parts of the brain are particularly responsive to experience at specific times or sensitive periods. Deprivation of required experiences, such as a lack of opportunity to form relationships or a lack of sensory experiences, is one way in which the brain can be organized in a dysfunctional fashion; another way is the overactivation of the neural systems involved in fear and stress which occurs when a child experiences a traumatic event.

Depending upon the age and gender of the child, and a variety of other circumstances, a response to trauma can take the form of hyperarousal or dissociation. Each has its own neurobiology, initial adaptive function for the child, and resulting psychiatric symptoms if the child responds habitually in that manner. Thus, a means of responding that was originally adaptive may become a “trait” resulting in externalizing or internalizing patterns of behavior. Because these coping patterns have become part of the brain's organization, the authors view children as malleable rather than resilient. That is, children have no choice but to adapt and may appear to recover, but the changes produced in the brain may result in lifelong problems. The authors drew a number of implications for intervention with maltreated children including the importance of early intervention to minimize the severity of the reaction to trauma and a healthy and responsive caregiver.

In contrast to his view of abuse as trauma, Perry (2002) defined neglect as “the absence of critical organizing experiences at key times during development” (pg. 88). From nonhuman animal studies on sensory deprivation and enrichment, clinical studies on institutional deprivation and the extent of recovery after placement in safe and enriching environments, and similar work from their own group on neglected children placed in foster care, he concluded that decreased sensory input results in cortical atrophy, enlarged ventricles, and small head size (measured by MRI or computerized tomography [CT] scans) particularly if the neglect occurs in more than one domain. Corroborative evidence was provided by Chugani et al. (2001) who studied post-institutionalized Romanian orphans using cognitive, language, and behavior measures as well as positron emission tomography (PET) to measure patterns of brain glucose metabolism. They found significantly decreased metabolism, compared with control groups, in limbic areas of the Romanian orphans' brains. The limbic system, including the amygdala, hippocampus, and hypothalamus, is involved in the regulation of emotional responses and the brain's response to stress; it can be damaged by prolonged stress. The absence of adequate social experience early in life may affect the development of these areas. Perry (2006) has developed a neurosequential therapeutic model to address the problems experienced by children as a result of both trauma and neglect; it will be described in the concluding section.

Finally, Glaser's (2000) comprehensive review was an attempt to integrate the neurobiology, developmental psychology, and psychiatric literatures as they related to child abuse and neglect. Given the number and complexity of the topics addressed, only a few major points will be summarized here. Glaser's intent was to review studies published during the previous 10 years from a variety of disciplines relevant to clinical work with maltreated children; however, most of them were not designed to address child maltreatment specifically. For example, she presented highly technical neuroscience material on the functioning of neurotransmitter systems related to the stress response, and integrated it with the developmental psychology of attachment relationships and their role in regulating infant arousal. To summarize what is known about the effects of abuse and neglect on the brain she described studies that have shown relationships between abuse and neglect, including sexual abuse and even maternal depression, on diverse measures of brain anatomy such as cerebral volume, size of the hippocampus, and functioning of the hypothalamic-pituitary-adrenal (HPA) axis which is central to regulating the stress response. It is noteworthy that she drew no conclusions from this research beyond the fact that there is evidence for differences in brain function that are associated with child maltreatment and that many of these appear to be related to stress. Perhaps this is because each study differed from the others in terms of the age of the subjects, abuse history, measurement, and design.

Glaser concluded that it is likely that different types of maltreatment produce different effects on the brain. Although caregiving relationships can buffer risk factors, in the case of child maltreatment,

the relationship itself can be a risk factor. She ended by emphasizing the importance of studying factors that lead to positive outcomes for maltreated children, and the need for active early intervention through changing parent-child interactions or adoption. Her assessment of the information from neuroscience is that it is quite helpful in explaining some of the difficulties seen in abused and neglected children, particularly those related to trauma. However, left unexplained is the way in which chronic emotional abuse and neglect produce effects on brain development; perhaps one way is by depriving the child of learning opportunities that shape neural connections.

The work of these scholars emphasizes that experiences of abuse, neglect, and other types of trauma may affect the development of brain systems that regulate responsiveness to stress in ways that may be maladaptive in terms of mental health. In addition, some types of maltreatment result in the lack of experiences required for typical brain development. In the following section we will discuss brain plasticity in more detail, emphasizing the distinction between the role of experience in contributing to brain structure and function during sensitive periods of development and its role in modifying the brain throughout the lifespan through learning and memory.

#### 4. Brain plasticity: The effect of experience on the brain

The view of the brain as an organ that is continually modified by experience, not only during infancy and childhood, but throughout life, is firmly supported by research and is becoming increasingly integrated into social science disciplines (e.g., Baltes, Reuter-Lorenz, & Rosler, 2006; Grossman, Churchill, Bates, Kleim, & Greenough, 2002; Huttenlocher, 2002; Rioult-Pedotti & Donoghue, 2003). Numerous areas of neuroscience research fall into the broad category of brain plasticity including the development of sensory systems in infancy, first and second language acquisition, the response of the brain to injury (e.g., Kolb, 1995), learning and memory, changes induced by motor learning, blindness, and stress, and the experience of phantom limb syndrome. A system for organizing and navigating the results of this research is therefore essential. The conceptual framework developed by Greenough and his colleagues that distinguishes between brain plasticity during childhood and adolescence and the ability of the brain to adapt to experience throughout life links the results of more than 50 years of nonhuman animal and human research with issues of child/human development including child maltreatment. Our summary of this framework is based primarily on the following sources: Black (2003); Black, Jones, Nelson, and Greenough (1998); Bruer and Greenough (2001); Greenough et al. (1987); Greenough and Alcantara (1993); Greenough and Black (1999).

The brain responds to experience in specific ways during different parts of the life cycle. Brain development before birth is the least influenced by experience. The sequence of prenatal brain development is controlled by gene expression, and by mechanisms of interaction among the developing parts of the brain (Marcus, 2003). Most of the neurons that an individual will ever have originate during the prenatal period through a process of overproduction and cell death. Neurons migrate to precise locations and then develop the axons and dendrites that will allow them to form connections with other neurons. For example, the six layers of the cerebral cortex are formed by the migration of neurons that crawl along radial glial fibers. Although the developing brain is protected from minor variations in the prenatal environment, it can be affected by nutrition, maternal stress, and teratogens such as alcohol (Huttenlocher, 2002; Nelson, de Haan, & Thomas, 2006).

At birth, the infant has billions of neurons, but most of the connections among them have not yet developed; two processes use experience in different ways to build those connections. Experience-expectant development involves the overproduction of synapses

(connections) in different parts of the brain at different times. Information entering from the environment then helps to organize this initial set of synapses by stabilizing some and letting others die. The experiences required for this process are almost always available to all members of a species and include light, sound, and social contact; the exceptions are conditions of severe maltreatment or deprivation or the malfunctioning of sensory organs through which experience enters the brain. Approximately half of these abundant synapses will be pruned as part of normal development in order to produce a brain that functions efficiently. Based on data obtained from human autopsy tissue (e.g., [Huttenlocher & Dabholkar, 1997](#)), it has been determined that synaptogenesis and pruning occur in the visual and auditory systems first, then in areas devoted to language, and finally in the prefrontal cortex, an area that continues to develop until early adulthood. Experience-expectant development involves sensitive periods, times when particular areas of the brain are highly responsive to particular types of experience.

The most frequently discussed example of experience-expectant development is the formation of the ocular dominance columns. The human newborn's visual system, similar to that of other species, requires patterned visual stimulation in order to develop binocular vision. If the infant's eyes are not functioning normally, such as when one is covered by a cataract or if the eyes do not point in the same direction, the part of the visual cortex that receives information from the eye that is receiving more stimulation will take over the part that would have been devoted to interpreting information from the other eye. Synapses will be pruned in a manner that does not support binocular vision and once this circuitry is in place it cannot be corrected simply by correcting eye functioning. [Tychsen \(2001\)](#) drew parallels between the experimental animal literature on visual experience and that of humans. The rise in visual acuity that typically occurs shortly after birth corresponds with the overproduction of synapses in the cerebral cortex as measured in infant autopsy tissue. To insure that infants whose eyes are not functioning properly receive the visual stimulation for normal visual acuity, depth perception, and motion tracking, surgery or other forms of correction must occur sometimes as early as five weeks after birth.

It is believed that the brain systems supporting other basic human sensory and motor functions develop in a similar manner, that is, through the overproduction of connections that are then pruned by experiences that are readily available to all members of a species (sights, sounds, opportunities to move and handle objects), and that must be available during distinct time periods to produce typical brain development. For these basic systems, it is more likely that development will go awry because sense organs are not operating properly (e.g., [Ponton, 2006](#)) than because the environment is lacking in appropriate stimulation. However, an exception is instances of extreme deprivation and neglect where the environment is so aberrant that it does not even provide sufficient stimulation to facilitate basic human development as exemplified by the circumstances of orphans in Romania and other Eastern European countries (e.g., [Johnson, 2000](#)).

Some aspects of language and social development are also characterized by sensitive periods, although the precise mechanisms by which experience-expectant development occurs are not well understood. Kuhl's research supports the idea that early language development involves neural commitment. As infants hear the sounds of their native language(s), they lose their initial ability to discriminate the phonetic contrasts of all languages; this loss appears to be necessary to facilitate learning one's native language ([Kuhl, 1999, 2004](#)). [Thompson \(2001\)](#) reviewed the literature on infant to parent attachment and concluded that there was much more support for the idea that there is a sensitive period for the development of any type of attachment than there is for the development of a specific type, such as secure attachment. That is, a certain set of species-typical experiences, such as being nurtured within a family group or by a

consistent set of caregivers might be required in order for the infant to develop an attachment at all; however, once developed, future experiences may allow for a change in its quality. Again, the experiences required for normal brain development are those that are readily available to all members of a species except in extreme circumstances such as deprivation and maltreatment. However, if those experiences are not available during sensitive periods, typical development may not occur; the provision of those experiences at a later time will probably not be as effective.

In contrast to experience-expectant development, which is thought to be completed by early adulthood, experience-dependent development is a lifetime process through which the individual's particular experiences (rather than those that are species-typical) are encoded in the brain through learning and memory. Rather than pruning unused connections, experience-dependent development involves the generation of new connections or the modification of existing ones. A large body of experimental work with nonhuman animals, including primates, has shown that living in complex environments composed of objects to explore and social stimulation, compared with typical laboratory cages, results in more synapses per neuron and differences in brain chemistry and weight in addition to improved performance on a variety of learning tasks (e.g., [Rosenzweig, 2007; van Praag, Kempermann, & Gage, 2000](#)). Moreover, the effect on the brain of specific training that leads to learning differs from the effect produced by the repetition of the same task. For example, after rats learned an acrobatic task they had more synapses per neuron than a group who had exercised on a running wheel; however, those who had engaged in the repetitive exercise had more blood vessels in specific areas of the brain (e.g., [Black, Isaacs, Anderson, Alcantara, & Greenough, 1990](#)). Although experience-dependent changes occur regardless of the age of the animal, they occur to a greater extent in younger animals.

Corroborating research with humans provides consistent support for brain plasticity in response to experience throughout life. Although it is not possible to measure changes or additions to synapses as can be done with nonhuman animals because this requires the examination of brain autopsy tissue, a variety of neuroimaging methods provides indirect evidence of such changes. Correlational studies have indicated that the types of experience involved in learning to drive a taxi ([Maguire et al., 2000](#)), play a musical instrument ([Elbert, Pantev, Wienbruch, Rockstroh, & Taub, 1995](#)), and read Braille ([Pascual-Leone et al., 1993](#)) are associated with changes in cortical maps (the amount of space in the cortex that is innervated by nerve cells from a particular part of the body) in the specific part of the brain thought to be most responsible for those activities. [Jacobs, Schall, and Scheibel \(1993\)](#) provided further evidence from human autopsy tissue that showed that attaining higher levels of education was associated with differences in Wernicke's area, an area that is heavily involved in language. This evidence is supported by laboratory studies in which people in experimental groups learned finger movement patterns through consistent practice. Learning produced changes in their cortical maps compared with control group participants who performed similar movements, but did not learn the patterns (e.g., [Karni et al., 1995; Robertson, Theoret, & Pascual-Leone, 2003](#)).

Both experience-expectant and experience-dependent brain plasticity occur during infancy and childhood but the former type predominates. By early adulthood, it is thought that pruning in the cerebral cortex is complete. Experience-dependent development, the modification and generation of new connections in response to experience, is then the process by which the brain continues to be affected by experience until death.

The neuroscience perspectives of [Cicchetti and Lynch \(1995\), Perry et al. \(1995\), and Glaser \(2000\)](#) on the effect of maltreatment and trauma on the development of stress reactivity and the potential for producing structural and functional changes in brain development

relates to experience-expectant plasticity. Perry (2002) also described the role of neglect in depriving children of the sensory experiences needed for early brain development. Perry was referring to lack of interaction and stimulation, but children could also be deprived of sensory experiences if problems with the functioning of their sense organs went undetected or untreated. This situation might occur more frequently in families where abuse and neglect occur. Aspects of vision, hearing, and language development may thus be at risk.

The concept of experience-dependent plasticity draws attention to the informal and formal learning that occurs during childhood that is individually and culturally specific rather than species wide. Such learning requires consistent routines, responsive interaction, and specific teaching, conditions that are less likely to be available in situations where maltreatment occurs. Instead, learning opportunities may revolve around surviving the abuse or neglect. Brain plasticity across the lifespan is also relevant for considering the impact of interventions for parents who must change their behavior in order to retain custody of their children. Although the brain retains the ability to change in response to experience throughout life, the stress experienced by these adults in their own lives may interfere with such learning (e.g., Sapolsky, 2003).

## 5. Recent reviews of maltreatment and stress system dysregulation

Numerous reviews that relate neuroscience research to child maltreatment have appeared since 2000 (e.g., Bremner & Vermetten, 2001; De Bellis, Hooper, & Sapia, 2005; Navalta, Tomoda, & Teicher, 2008; Nemeroff, 2004; Tarullo & Gunnar, 2006; Teicher et al., 2003; Van Voorhees & Scarpa, 2004; Watts-English, Fortson, Gibler, Hooper, & DeBellis, 2006), and nearly all of them have focused on the link between maltreatment and the dysregulation of the stress system. Such dysregulation, which depends upon numerous aspects of an individual's experience, such as the quality of attachment with primary caregivers (Van Voorhees & Scarpa, 2004), can set the stage for depression, anxiety, and other mood disorders in childhood and adulthood as well as a host of health problems. It can be considered experience-expectant development because it involves the crucial role of early experience in guiding brain development in ways that make the individual more or less sensitive to possible threat in the environment and thus more or less likely to engage the stress system throughout life.

In order to present a broad overview of an extremely complex area, we will summarize the major topics covered in three recent reviews (Nemeroff, 2004; Tarullo & Gunnar, 2006; Teicher et al., 2003) that focus on different aspects of the literature that link the experience of maltreatment with stress system dysregulation. A brief and very basic description of the functioning of the stress system, based on those reviews, provides necessary background information.

The HPA axis plays a central role in the organism's response to threat, although other areas of the brain, such as the prefrontal cortex and the sensory and association cortices, are critical for tasks such as interpreting information from the outside world and linking it with memories (e.g., Houshyar & Kaufman, 2005). When a threat is recognized, the hypothalamus releases corticotropin releasing factor (CRF) which, in turn, stimulates the pituitary gland to release adrenocorticotropic hormone (ACTH) which results in glucocorticoid (cortisol) release from the adrenal gland. Behavioral responses that accompany these secretions include increased heart rate and blood pressure, disturbed sleep and other indications of anxiety. Although cortisol initially increases arousal, energy, and concentration, it also serves to help terminate the body's response to threat through a negative feedback system. The hippocampus, which is essential for memory, is an important part of this system; it contains cortisol receptors that help stop the additional release of CRF from the hypothalamus. Cortisol is thus essential for the smooth functioning of the system, but it can have deleterious effects on learning, memory,

and other cognitive functions, particularly if the individual experiences chronic stress (e.g., Bremner, 2005; Sapolsky, 2003). The HPA system as a whole is, of course, essential for survival but, if activated chronically, can have detrimental effects on numerous aspects of health, including mental health (e.g., Sapolsky, 1999).

Evidence presented in the three reviews summarized below indicates that there is good reason to suspect that the stress of maltreatment during childhood, in conjunction with genotype, produces dysregulation of this finely balanced system while it is still developing so that it is prone to overreact throughout life, increasing the individual's risk of developing anxiety, depression, and other mood disorders. Dysregulation can result in the production of too much or too little cortisol and a variety of other hormones and neurotransmitters. The situation is complicated even further because brain cells can respond to the abundance of a substance by downregulating the number of receptors for that substance. That could mean that the hypothalamus receives less negative feedback from the hippocampus because there are fewer cortisol receptors there. That could result in more production of CRF and an even more prolonged response to a stressful event. (See Gunnar & Vasquez, 2006 for a comprehensive description of the stress system as it relates to psychopathology.)

In their review, Teicher et al. (2003) argued that the stress experienced from abuse and neglect can impact brain development, producing differences in its anatomy and functioning that may result in psychiatric disorders. Two major avenues by which this can occur include making the brain more responsive to possible threats in the environment and modifying typical processes of brain development including neurogenesis, synaptic overproduction and pruning, and myelination (laying down of a fatty sheath around axons that results in more efficient communication among neurons) resulting in a brain that is different from one that develops in the absence of abuse and neglect. Brain regions that may be particularly vulnerable to stress are those that have a long period of development, a high density of glucocorticoid (cortisol) receptors, and the production of new neurons after birth, such as the hippocampus.

Studies with nonhuman animals and human children and adults were presented in four major sections of the Teicher review: 1) differences in the neuroanatomy of the hippocampus, amygdala, corpus callosum, cerebellar vermis, and cerebral cortex associated with maltreatment status; 2) the functional consequences that could follow from these anatomical differences based on the typical functions of these areas; 3) sex differences in the nature and consequences of adverse early experience; and, 4) an argument for conceptualizing these brain differences as part of an alternate developmental pathway taken in response to the individual's experience of the environment rather than a manifestation of pathology.

The authors clearly stated that human research on the association between maltreatment and brain development is in a nascent stage, and it is apparent that the results at this point are not clear-cut. For example, there is evidence that early stress may interfere with the normal development of the hippocampus, which is critical for episodic memory, perhaps making an individual vulnerable to amnesia and dissociation, symptoms of PTSD. However, it may also be the case that a hippocampus that is small for other reasons is a risk factor for developing PTSD in response to stressful circumstances. De Bellis et al. (2005) found that hippocampal differences are not seen in studies of childhood PTSD, but are seen in studies with adults, perhaps because stress produces its effects only gradually so that they are not apparent until after puberty. The smaller hippocampi seen in adult PTSD may also be related to substance abuse.

The most convincing evidence for the effects of stress on brain development pertains to the corpus callosum. High levels of stress hormones can interfere with the myelination of corpus callosum axons during their development by suppressing the division of glial cells that produce myelin. This makes the axons less efficient in

conducting nerve impulses between the two hemispheres of the brain. Three separate studies with abused or neglected children are described that linked maltreatment with reduction in corpus callosum size (refer to [Teicher et al., 2004](#), described in the introduction of this article for a more recent example).

Finally, the authors distinguished their earlier conceptualization of the effects of stress on the developing brain from their revised view. Earlier, they thought of such effects as developmental insult or atypical development that resulted in enduring deleterious consequences for the individual. Their revised view is that there is a sensitive period during early development when exposure to high levels of stress hormones produces a cascade of neurobiological effects that guide the brain to develop in ways that make it more responsive to threat. The advantage of that developmental path is perhaps a greater chance to survive and reproduce under conditions of deprivation and danger. The disadvantage is that such stress responsiveness may not provide an advantage in benign circumstances and carries the risk of developing medical and psychiatric disorders (see also [Navalta et al., 2008](#)). The authors concluded by calling for attention to emotional maltreatment and corporal punishment, the use of imaging technologies to clarify effects of stress on white matter (axons), and the possibility that treatment can reverse the effects of abuse and neglect on brain development.

[Nemeroff \(2004\)](#) provided a somewhat different perspective by reviewing research on the impact of early experience on the functioning of the CRF system (part of the HPA-axis). A major portion of his review focused on rat and primate models of early experience, in which both prolonged maternal separation and quality of maternal care were experimentally manipulated. The findings from this body of research provide clues about the way in which adverse events in children's early lives influence the functioning of stress-related neurotransmitter systems which then increase vulnerability to stress-related disorders. He then reviewed studies that linked the occurrence of mood and anxiety disorders in human adults to early life stressors. For example, he described a study conducted by his research group ([Heim et al., 2000](#)) that showed that women who had been abused in childhood had greater ACTH and cortisol responses to mild stressors (public speaking or mental arithmetic) than either depressed women without a history of abuse or a control group.

The general conclusion that can be drawn from examining rat and primate research is that prolonged separation of infants from their mothers, which is conceptualized as trauma, results in adult animals that are likely to be more responsive to threat in adulthood, measured by both behavioral responses and the functioning of the CRF system. However, another body of research involves a rat model of variation in the quality of maternal care which sheds additional light on the origins of stress responsiveness. [Nemeroff](#) mentioned, but did not elaborate on this body of work; therefore, information was obtained from additional sources for the following summary (e.g., [Francis, Diorio, Liu, & Meaney, 1999](#); [Meaney, 2004](#); [Parent et al., 2005](#)).

High quality maternal care in the rat involves abundant licking, grooming, and arched-back nursing of rat pups. The amount of this care can be increased experimentally by briefly separating pups from their mothers, handling them, and then returning them. However, it also varies naturally across rat mothers as ascertained by observations of mothers and pups that are left undisturbed. Numerous studies have shown that the amount of licking, grooming, and arched-back nursing experienced by pups during a sensitive period in early post-natal life results in differences in the pups' stress reactivity which persists throughout life. Rats who experienced more high quality care from their mothers became adults who were less responsive to threat than the offspring of mothers who provided less of the high quality care. The pups, in turn, were more likely to provide similar care for their own offspring, that is, "anxious" rats were more likely to provide less high quality care than "relaxed" rats. Cross-fostering studies confirmed that it was the maternal care and not genetic similarities

between a mother and her offspring that were responsible for this intergenerational transmission. High quality rat maternal care produces additional benefits such as synaptogenesis in the hippocampus and enhanced spatial learning and memory ([Liu, Diorio, Day, Francis, & Meaney, 2000](#)).

One of the mechanisms by which high quality care produces these results is by preventing the methylation of a gene that is involved in the production of glucocorticoid receptors in the hippocampus (Methylation is the marking of a gene that prevents its expression). If the gene is not marked, more receptors are produced, contributing to better feedback in the HPA system. The feedback helps terminate the stress response, resulting in a rat that is more "relaxed". In addition to the tendency to react more or less strongly to threat that results partially from the type of care received from their own mothers, mother rats also respond to their current environments; stressful life circumstances can result in less licking and grooming even in "relaxed" mothers. The quality of care received by an infant rat can thus communicate information about the privations and dangers present in the current environment, thus preparing the infant to respond in ways that promote survival, a view similar to that presented by [Teicher and his colleagues \(Navalta et al., 2008; Teicher et al., 2003\)](#). The possibility that such epigenetic mechanisms operate in human development is the subject of the following review.

[Gunnar and her colleagues](#) reviewed research on the functioning of the HPA axis during early childhood from the perspective of their own decades-long research program that has relied on the measurement of salivary cortisol. In their review, [Tarullo and Gunnar \(2006\)](#) focus first on the fact that the HPA axis is not fully developed at birth; its functioning is under social regulation during infancy and early childhood, and this regulation is mediated through sensitive and responsive caregiving. If this type of care is not available, then the HPA axis may develop in an atypical manner.

Although newborns respond to aversive situations with increases in cortisol, this response decreases during the first year of life even though behavioral indicators of distress still occur. The authors equate this hyporesponsive period to a similar post-natal period in the development of the rat which may help protect the brain from elevated stress hormones. Protection from these hormones in both the rat and human is mediated by parental care, however. The authors described a series of human studies that link sensitive, responsive care of infants and their secure attachment to caregivers to the absence of a rise in cortisol after separation from the primary caregiver during the Strange Situation assessment (The Strange Situation measure involves the observation and coding of toddlers' responses to a series of episodes in which the mother and/or a stranger is present or absent. The results of this measure have been linked with quality of care and future development in an extensive series of studies). Maltreated toddlers, on the other hand, are more likely to be insecurely attached; they alternately approach and avoid the caregiver, perhaps indicating that the caregiver is both a threat and potential source of comfort. Several studies have found high cortisol levels in these maltreated toddlers after separation. These studies support the hypothesis that the activity of the HPA system in early childhood is socially regulated and that dysregulation may accompany maltreatment.

The authors then argued for the importance of studying children raised in naturally occurring situations of deprivation because of the difficulties of interpreting the data obtained by studying adults who were maltreated as children. One of these difficulties is that the current functioning of their HPA axis may be more related to their current life circumstances of high stress and low support than of differences in brain development produced by adverse experiences early in life. Prospective studies of children raised in Russian and Romanian orphanages, are thus very important. Research conducted with these children, using salivary cortisol as a measure, provides evidence for the dysregulation of the HPA system early in life. These children show an absence of the typical diurnal fluctuation in levels of

cortisol found in home-reared children, that is, they do not show the early morning peak followed by decreases over the day that children raised in family situations do. Orphanage-reared children who are then adopted show a rebounding of HPA function and somewhat typical diurnal cortisol fluctuations. There is also evidence that blunted cortisol rhythms are present in some children entering new foster care placements and in children who experience care from insensitive child care staff.

Tarullo and Gunnar (2006) also provided an extensive discussion of a methodological issue that may be responsible for the complexity and seeming contradictions in the results from studies of adults who were maltreated as children and maltreated children studied while they are children. For example, research conducted on adults uses a stress reactivity method where the individual may be given a challenge, such as public speaking or similar task, and the effects on different hormones involved in stress are measured. On the other hand, research on maltreated children has focused on basal levels of cortisol rather than on challenges. The results of studies on both adults and children are complex and inconsistent and depend on the current diagnosis or disorder, gender, and type of abuse.

The authors concluded this review by asking if enough information is available to begin to target parts of the HPA system with drugs and they conclude that not enough consistent information is available to warrant this type of intervention. Changing the environment, however, by training foster parents to be more sensitive and responsive, has been shown to restore the typical cortisol rhythm, reduce basal cortisol levels, and reduce behavior problems compared with children whose foster parents did not receive the intervention.

This result and other evidence suggest that various interventions at various points in time may mitigate the adverse effects of child maltreatment or high risk environments on brain development. The most obvious need is primary prevention. That is, if parents with high risk factors are exposed to evidence-based programs, child maltreatment can be prevented, and negative related brain development sequel averted. Some programs have been effective with expectant mothers (Olds, Eckenrode, & Kitzman, 2005); others have worked with high risk parents of children ages birth-5 (Whitaker, Lutzker, Self-Brown, Edwards, 2008). There are a number of evidence-based practices that have been shown to reduce risk for children whose parents have been referred for child maltreatment. Most of these programs focus on teaching parents skills in positive child behavior management (Bugental et al., 2002; Chaffin, et al., 2004; DePanfilis & Dubowitz, 2005; Gershater-Molko, Lutzker, & Wesch, 2003; Prinz, Sanders, Shapiro, Whitaker & Lutzker, 2009; Webster-Stratton, 1994). One program, SafeCare®, also teaches child health care skills and how to “child-proof” a home, to avoid the safety and filth hazards for which many parents are referred for neglect (Edwards & Lutzker, 2008). In addition to more research examining long-term social and academic outcomes of high risk children and children whose parents have been referred for abuse or neglect, it may be possible in the future to determine if measures of brain functioning are sensitive to such evidence-based interventions.

## 6. Summary and implications

Seminal and more recent neuroscience perspectives on child maltreatment converge on the idea that the brain can respond to the stress of abuse and neglect by developing in a way that leads to heightened responsiveness to threat throughout life with possible consequences for survival, mental health, learning, and physical well-being. The impact of early experience on the functioning of the HPA axis is the focus of much of the current neuroscience research pertinent to child maltreatment. However, abuse and neglect can have more widespread effects on brain development and functioning because of the deficits in stimulation, interaction, and learning opportunities experienced by these children. Although there does appear to be a general consensus about these points, the details about

the precise effects on the human brain and the extent to which they might be reversed or modified by intervention are still far from clear.

Recommendations for prevention and intervention made from neuroscience perspectives, such as insuring that children experience sensitive and responsive care and are protected from further neglect and abuse, support those emanating from numerous therapeutic approaches. However, it may be the case that information about maltreatment effects on brain development, which may be very difficult to modify, lend particular urgency to those recommendations and to the prevention of maltreatment by supporting families in the task of parenting. Cicchetti (2007) states that the prevention of child maltreatment must be a national priority and that researchers must keep policymakers informed about the biological consequences that have implications for a range of issues from academic difficulties to the intergenerational transmission of abuse. He advocates implementing intervention for children as soon as maltreatment is discovered rather than waiting until the child is diagnosed with a disorder.

As mentioned earlier, the results of neuroscience research are beginning to be integrated into the therapeutic literature to explain how an approach might be working, to justify its use, or to modify it. Perhaps the best example of a therapeutic approach based upon a particular view about how the developing brain is affected by maltreatment is the Neurosequential Model of Therapeutics (Perry, 2006). Perry and his colleagues developed it to replace the traditional medical model they had been using which consisted of psychopharmacological, individual, family, and group therapies. The question is whether therapeutic experiences can be developed to promote healing and recovery from the damage caused to brain development by adverse experiences. Perry draws clinical implications from six key principles of neurodevelopment and these form the foundation for therapy. For example, one principle relates to *the importance of patterned, repetitive, enriched, nurturing experiences that should occur during sensitive periods of brain development*. If a child experiences chronic or traumatic stress or is neglected, the brain will develop but in ways that reflect such exposure. The clinical implication derived from this principle is the importance of the repetition of replacement experiences that are directed to those regions of the brain that mediate the stress response or those that were not sufficiently stimulated due to neglect. He emphasized that the number of repetitions required may be extremely frustrating for adoptive parents and teachers and certainly cannot be provided during therapy hours. It is also the case that, although the brain retains the ability to be changed by experience throughout life, some brain systems, such as those involved in mediating the stress response, may be much more difficult to modify than others after sensitive periods have ended.

It is not only children who are the focus of therapy for abuse and neglect. The adults who perpetrated the maltreatment, who may themselves have been victims of abuse, are viewed as individuals who can learn to manage their family life and interact with their children so that there is less chance for the maltreatment to recur. The relevance of a neuroscience perspective for conceptualizing therapeutic changes in the maltreating parent and other adults does not seem to have been explored. While there is abundant evidence that adult brains change with experience, it is also the case that stress is an experience too and that it can interfere with learning. Sapolsky (2003) refers to the effects of stress as brain plasticity's dark side because chronic or overwhelming stress can result in damage to neurons in the hippocampus, a structure essential for memory functions. Neuroscience research on the relationship between stress and learning could provide a useful perspective on the difficulties of providing successful therapeutic programs for parents who are experiencing severe stress which is probably affecting the quality of care they can provide for their children.

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