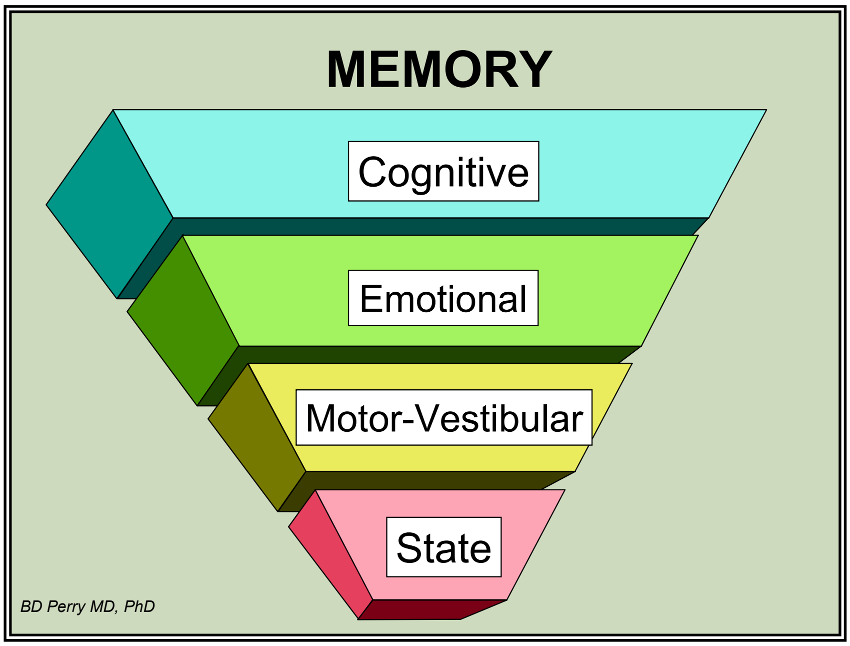
Brain Structure and Function II

Special Topics Informing Work with Maltreated Children



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This booklet is one in a series developed by the ChildTrauma Academy to assist parents, caregivers, teachers and various professionals working with maltreated and traumatized children.

Interdisciplinary Education Series
Edited by B. D. Perry

Adapted in part from: *"Maltreated Children: Experience, Brain Development and the Next Generation"* (W.W. Norton & Company, New York, in preparation)

Introduction

A terrified 3-year-old child huddles, sobbing, in a dark corner of his room after being beaten by a drunken parent for spilling milk. A 'colicky' infant cries for 8 hours, left alone, soiled and hungry, by an immature, impaired mother. A 7-year old boy watches his father beat his mother, the most recent of many terrorizing assaults this child has witnessed in his chaotic, violent household.

Terror, chaos and threat permeate the lives of too many children – millions of children across the globe each year have tiny pieces of their potential chipped away by fear. Fear inhibits exploration, fear inhibits learning, and fear inhibits opportunity. And when it does, it changes the child. It changes the brain of that child.

In order to understand what is happening inside these children, what is changing in their brains, what is changing in their minds we need to understand some of the basic organizational and functional properties of the human brain. The first booklet in this series covered the core elements of brain structure and organization that serves as a background for this booklet.

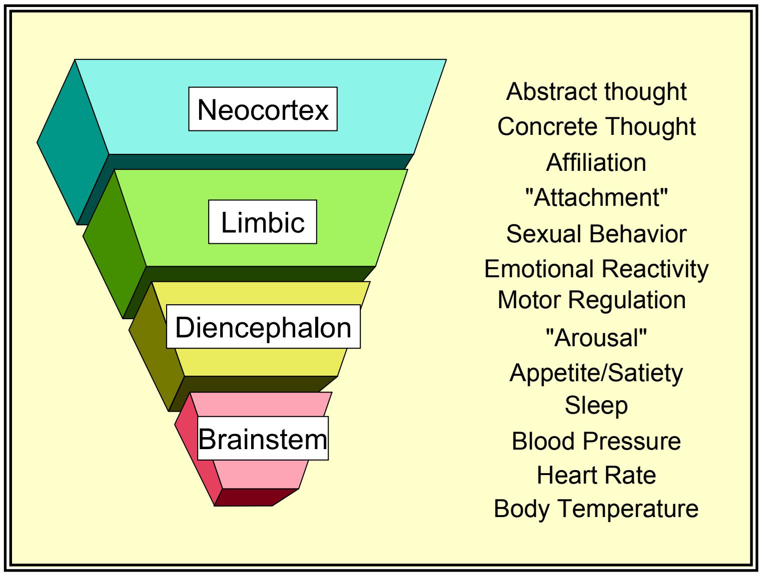
The purpose of this booklet is provide an overview of some of the key features of the brain that are directly influenced by trauma, neglect or fear. The majority of professionals working with maltreated children do not have a background in biology or the neurosciences. This booklet is targeted at the wide group of non-neuroscientists working with maltreated children. Understanding of the rudiments of human brain function and brain development can provide very useful and practical insight to the, all-too-often, puzzling emotional, behavioral, cognitive, social and physical problems that the interdisciplinary team faces when working with maltreated children.

Key Brain Systems Involved in Threat, Fear and Trauma

In order to understand the traumatized child we must understand the fear response. The human brain has a very elaborate and important set of neural systems involved in the response to threat. Indeed, it is the abnormal persisting activation of these systems that appears to lead to many of the symptoms seen in maltreated children. The next section will provide an overview of the key brain systems regulating the stress response.

There are many neurotransmitters involved in the stress response. Some of the most important are clusters of intrinsic neurons that use the monoamine neurotransmitters epinephrine, norepinephrine, dopamine and serotonergic. These systems, despite comprising only a minor fraction of the brain's neurons, have disproportionate "power" to regulate human behavior, emotional functioning and cognition. This is because these systems originate in the brainstem and have connections in virtually all brain areas. Collectively, the brainstem monoamines regulate and mediate hundreds of crucial functions – including the complexities of the stress response.

The Reticular Activating System: Brainstem: The network of ascending arousal-related neural systems in the brain consisting of locus coeruleus noradrenergic neurons, dorsal raphe serotonin neurons, cholinergic neurons from the lateral dorsal tegmentum, mesolimbic and mesocortical dopaminergic neurons, among others, form the reticular activating system (RAS). A great deal of the original research on arousal, fear, response to stress and threat was carried out using various lesion models of the RAS. The RAS plays a major role in arousal, anxiety and modulation of limbic and cortical processing. These brainstem and midbrain monoamine systems, working together, provide the flexible and diverse functions necessary to modulate the variety of functions related to anxiety regulation.



Hierarchy of Brain Function: The human brain is organized from the most simple (e.g., fewest cells: brainstem) to most complex (e.g., most cells and most synapses: frontal cortex). The various functions of the brain, from most simple and reflexive (e.g., regulation of body temperature) to most complex (e.g., abstract thought) are mediated in parallel with these various areas. These areas organize during development and change in the mature brain in a 'use-dependent' fashion. The more a certain neural system is activated, the more it will 'build in' this neural state -- creating an internal representation of the experience corresponding to this neural activation. This use-dependent capacity to make internal representations of the external or internal world is the basis for learning and memory.

Locus Coeruleus: A critical brain stem nuclei involved in initiating, maintaining, and mobilizing the total body response to threat is the locus coeruleus (LC). This bilateral grouping of norepinephrine-containing neurons originates in the pons and sends diverse axonal projections to virtually all major brain regions, enabling its function as a general regulator of noradrenergic tone and activity. The LC plays a major role in determining the 'valence' or value of incoming sensory information, increasing in activity if the information is novel or potentially threatening. The ventral tegmental nucleus (VTN) also plays a part in regulating the sympathetic nuclei in the pons/medulla. Acute stress results in an increase in LC and VTN activity and release of norepinephrine that influences the brain and the rest of the body. These brainstem catecholamine systems (LC and VTN) play a critical role in regulating arousal, vigilance, affect, behavioral irritability, locomotion, attention, the response to stress, sleep and the startle response.

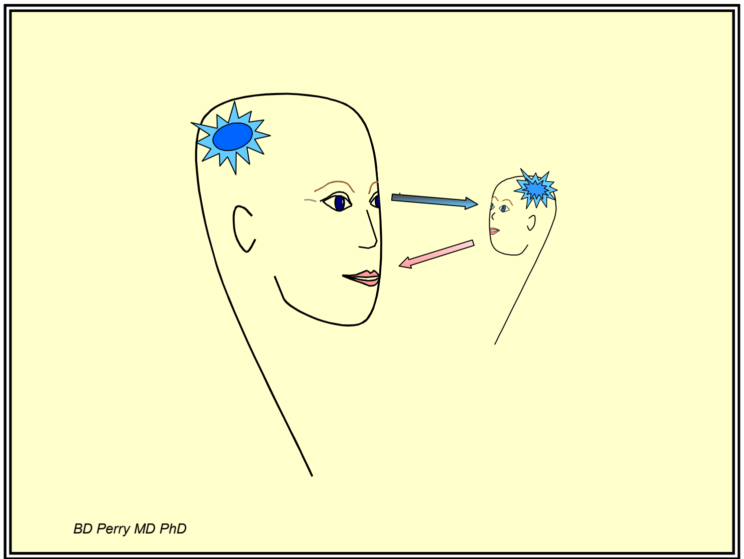
Hippocampus: The hippocampus is a crucial brain formation located at the interface between the cortex and the lower diencephalic areas. It plays a major role in memory including what we call episodic, declarative and spatial learning and memory. In addition it plays a key role in various activities of the autonomic nervous and neuroendocrine systems. Stress hormones and stress-related neurotransmitter systems (i.e., those from the locus coeruleus and other key brainstem nuclei) have the hippocampus as a target. Various hormones (e.g., cortisol) appear to alter hippocampus synapse formation and dendritic structure, thereby causing actual changes in gross structure and hippocampal volume as defined using various brain imaging techniques. Repeated stress appears to inhibit the development of neurons in the dentate gyrus (part of the hippocampus) and atrophy of dendrites in the CA3 region of the hippocampus. These neurobiological changes are likely related to some of the observed functional problems with memory and learning that accompany stress-related neuropsychiatric syndromes, including Post-traumatic stress disorder (PTSD: see Academy Volume 2, Number 4).

Amygdala: In the recent past, the amygdala has emerged as the key brain region in the processing, interpreting and integration of emotional functioning. In the same fashion that the LC plays the central role in orchestrating arousal, the amydgala plays the central role in the CNS in processing afferent and efferent connections related to emotional functioning. The amygdala receives input directly from sensory thalamus, hippocampus (via multiple projections), entorhinal cortex, sensory association areas of cortex, polymodal sensory association areas of cortex, and from various midbrain and brainstem arousal systems via the RAS. The amygdala processes and determines the emotional value of simple sensory input, complex multisensory perceptions and complex cognitive abstractions, even responding specifically to complex, socially relevant stimuli. In turn, the amygdala orchestrates the response to this emotional information by sending projections to brain areas involved in motor (behavioral), autonomic nervous system and neuroendocrine area of the CNS. In a series of landmark studies, LeDoux and colleagues have demonstrated the key role of amygdala in 'emotional' memory. Animals, including humans, store information other than cognitive, and the storage of emotional information is critically important in normal and abnormal regulation of anxiety. The 'site' of perception of anxiety is likely to be the amygdala. It is in these limbic areas that the patterns of neuronal activity associated with threat, and mediated by the monoamine neurotransmitters systems of the reticular activating system, become an emotion.

Cortex: The quality and intensity of any emotion, including anxiety, is dependent upon subjective interpretation or cognitive appraisal of the given situation. Most theories addressing the etiology of anxiety disorders discuss the process of 'mislabeling' of stimuli as being 'threat'-related, thereby inducing a fear-response and anxiety in situations where no true threat exists. How an individual cortically-'interprets' the limbic-mediated activity (i.e, their internal state) associated with arousal plays a major role in the subjective sense of anxiety. Kluver-Bucy syndrome, resulting from damage or surgical ablation of temporal lobes results in loss of fear for current and previously threatening cues. The general disinhibition of this syndrome suggests a loss of the capacity to recall cortically-stored information related to previous threat, or to efficiently store threat-related cues from new experience.

Other areas of the cortex play a role in threat, primary among these are the primary and multimodal association areas which have direct connection to the amygdala. Important neurotransmitters in cortical, as well as other regions involved in threat are GABA and glycine. The capacity of benzodiazepines to alter arousal and sensitivity to threat has long been known. Indeed in humans, primary pharmacological treatment for many anxiety disorders involves benzodiazepine treatment, targeting GABA receptor complexes. While the GABA binding sites are ubiquitous in the CNS, the specific primary region for the therapeutic effects of benzodiazepines is unknown. It is likely that therapeutic effects are the result of action in multiple areas of the brain, including the cortex.

Special Topics: Communication and Affiliation



Socio-emotional communication: Central to the invisible biological processes that allow social interaction is communication -- the capacity to perceive and understand others and to express meaning and intention to others. As might be expected, after thousands of generations, the human brain developed remarkable biological apparatus dedicated specifically to 'social' perception and communication, verbal and non-verbal. Just as there is are parts of the brain responsible for moving, others for seeing or hearing, there are systems in our brains that are dedicated to social-affiliation and communication. These parts of the human brain are organized, in part, by the somatosensory experiences of early life. Eye contact, rocking, cooing, smiling – all are translated by the sensory organs into patterns of neural activity. In turn these patterns are processed in lower parts of the brain and the organized, categorized patterns of activity converge in various sub-cortical and cortical areas (e.g., supraorbital prefrontal cortex, cingulate gyrus) where these waves of neuronal signals help organize these brain areas.

Communication between one human and another is the hallmark of our species. Communication was the critical capacity required for survival during the thousands of generations of our evolution. Naked, slow, weak and without biological armor or weapons, humans survived by living and hunting in groups. Interdependent individuals created a strong, flexible and adaptive 'whole' – the band, the clan, the tribe.

While physically separate and self-aware, individual humans are linked by the invisible, yet biological, bonds of sensation, perception and communication into larger biological units – collections of individuals -- groups. One individual may belong to many groups,– a couple, a family, a working group – each with unique and dynamic properties. Each group has a set of tasks and a set of rewards for the individual and, as a whole, the integrity and function of the group is formed, maintained and changed by social interaction.

Central to the invisible biological processes that allow social interaction is communication -- the capacity to perceive and understand others and to express meaning and intention to others. As might be expected, after thousands of generations, the human brain developed remarkable biological apparatus dedicated specifically to 'social' perception and communication, verbal and non-verbal. These underlying biological properties are continually 'at play' in all human interactions – sensing, processing, perceiving, storing and acting on signals from other humans. All human interactions are governed by core principles of communication that, in turn, are the product of neurobiological processes shaped by thousands of years of evolutionary pressures.

During the thousands of generations of the early history of our species, we lived in small bands – twenty to fifty members. Individual survival depended upon cooperation and communication. The remarkable expressive communication capacity of the face was further refined. Facial expression become the most important of all social communication 'instruments.' Facial expressions have the capacity to reflect the internal emotional state of the individual, and elicit a specific emotional and social response from an individual – smile, frown, glare, snarl, ignore, stare, come hither, get lost. The face expresses pain, ecstasy, anger, fear, doubt, confidence and threat.

During the development, each person creates catalogue of familiar faces, the faces of the family and the band, and stores these as templates for familiar/safe. And in these familiar faces, the infant and child learn the non-verbal language of the group – as surely as they learn the verbal language. An unfamiliar face will elicit a low-level alarm response in any individual – all new faces are judged to be threatening until proven otherwise. This is due to two main factors. The first is that, in general, the brain's information matching process is very conservative. All novel situations and new information are judged to be threatening until proven otherwise. The second, and most powerful, specific reason that new faces elicit a low level alarm is that the human brain evolved in a world where for thousands of generations, the major threats to any individual were other humans - humans from other clans. A new person, a new face in the typical interaction from 100,000 years ago to 5,000 years ago meant that there were other humans around – competing for the same water, fruits, game, and cave. This new person was as likely to attack you, drive you away, steal your camping site, take the young and rape the women of your band, as they were to decide to affiliate or cooperate. Across generations, wariness to new individuals, new groups and new ideas was selected and built into the circuits of the human brain's alarm-response.

Over hundreds of thousands of years, proto-hominids and human beings lived in hunter-gatherer bands with thirty to forty members. Thus, the biological 'capacity' for the number of familiar/safe faces was quite small. And these template faces and facial features of 'same'/safe/familiar, like all other templates for emotional, behavioral and social functioning, are set during childhood. This tendency to have an alarm response when exposed to an unfamiliar face or mismatched facial features is the root of many human behaviors. For example, despite very minor (millimeter) differences in where facial features are placed, almost all people can immediately recognize the difference in a Down's syndrome child. This matching against previous template faces is at the root of racism (and a strong argument why children of different races should be together in school and play – allowing them to build in diverse set of internal templates of what is same/safe/familiar).

This capacity to match diverse information against previous templates of multisensorial input is also at the root of recognition of deceit. When words do not match with body movement, facial expression, the tone of voice, the brain 'senses' a multisensory mismatch ('usually when some says "I love you", there are accompanying non-verbal signals eye contact, facial, body movement—or when someone is 'telling the truth'). This is, of course, why children raised with caregivers who talk the talk but don't walk the walk (e.g., domestic violence, multiple foster homes) internalize patterns of communication and interaction which are very distorted and often destructive (talk about association of intimacy, power, violence, threat,). And why, so often, children raised in these deceitful settings, can so easily lie without detection – they have not internalized the same non-verbal templates associated with deceit. For these children, the development of sociopathic characteristics is merely an adaptation to the deceitful, inconsistent and unrewarding world their caregivers have created for them.

Through these thousands of generations of evolutionary selection, the brain developed the capacity to read non-verbal cues – many of which are communicated via changes in facial expression. The brain has special face and expression recognition capabilities – and through a process of 'matching' expressions and faces with previous known faces and expressions, makes decisions about the familiarity and intentionality of the specific interaction.

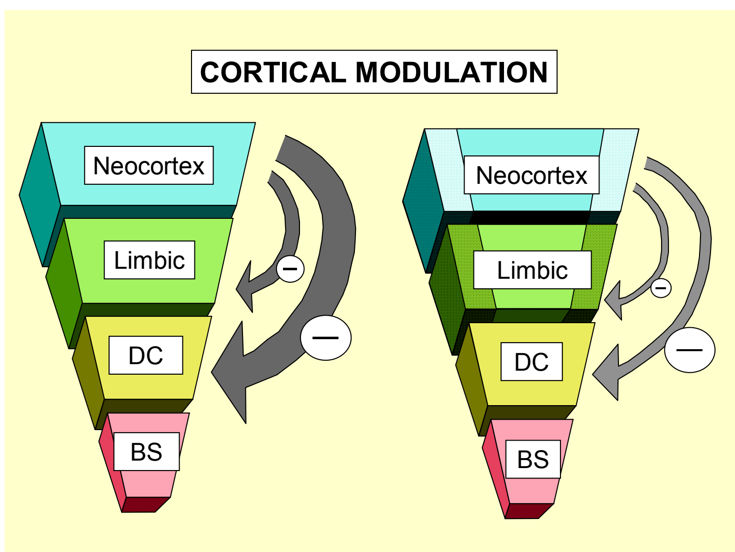
Because we have a limited capacity for categorizing and matching specific faces and facial expressions, the brain uses other body movements, postures, and other symbolic trappings of recognition (e.g., clothes, uniforms, style of hair cut), to make secondary decisions about recognition. You may not recognize the face but the haircut, clothes, manner of interaction can readily identify someone as "familiar/good" or as "familiar/bad." This categorizing tendency, of course, is the basis for a host of well-described and common phenomenon in human interaction – including first impressions or using 'known' celebrities to sell products or ideas. A classic example of this in the mental health field is transference. This is phenomenon of attaching <u>multiple</u> attributes of a past relationship to one in the present when only one of those attributes may truly be present (e.g., reacting to a male therapist with the intensity that was present in a paternal relationship).

Special Topics: Cortical Modulation

The human brain works, largely, through inhibitory mechanisms. The structural organization and functional capabilities of the mature brain develop throughout life; the majority of structural organization takes place in childhood. This development is characterized by 1) sequential development and 'sensitivity' -- from the brainstem to the cortex and 2) 'use-dependent' organization of these various brain areas.

As the brain grows and organizes from the "inside-out" and the "bottom-up" the higher, more complex areas begin to control and modulate the more reactive, primitive functioning of the lower parts of the brain. The person becomes less reactive, less impulsive, more 'thoughtful.' The brain's impulse-mediating capacity is related to the ratio between the excitatory activity of the lower, more-primitive portions of the brain and the modulating activity of higher, sub-cortical and cortical areas. Any factors which increase the activity or reactivity of the brainstem (e.g., chronic traumatic stress) or decrease the moderating capacity of the limbic or cortical areas (e.g., neglect, brain injury, mental retardation, Alzheimer's, alcohol intoxication) will increase an individual's aggression, impulsivity and capacity to be violent (see below). A key neurodevelopmental factor that plays a major role in determining this moderating capacity is the brain's amazing capacity to organize and change in a 'use-dependent' fashion.

The capacity to moderate frustration, impulsivity, aggression and violent behavior is age-related. With a set of sufficient motor, sensory, emotional, cognitive and social experiences during infancy and childhood, the mature brain develops - in a use-dependent fashion --a mature, humane capacity to tolerate frustration, contain impulsivity and channel aggressive urges.

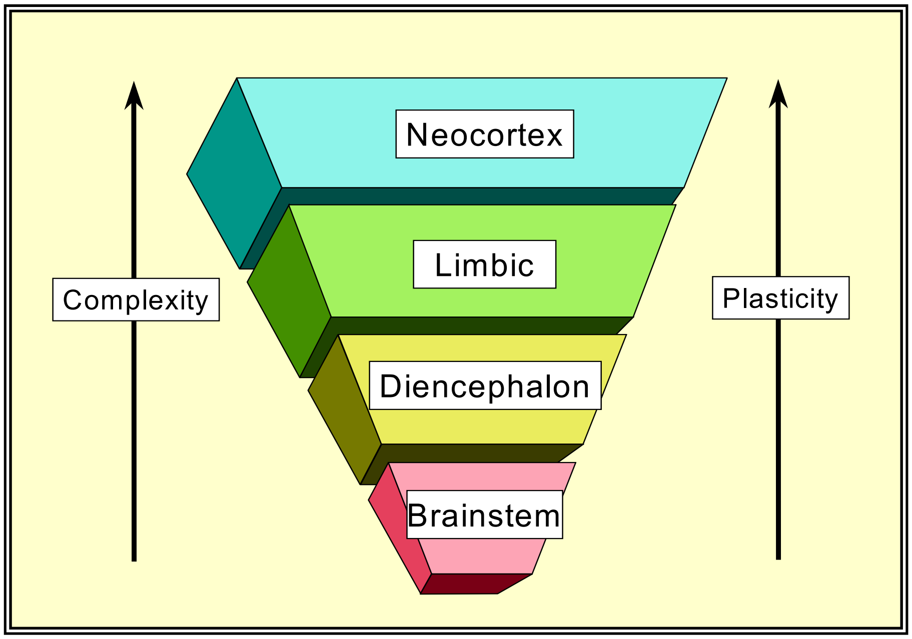


Cortical Modulation: As the brain develops in this sequential and hierarchical fashion, and the more complex limbic, sub-cortical and cortical areas organize, they begin to modulate, moderate and 'control' the more primitive and 'reactive' lower portions of the brain (Figure 2). These various brain areas develop, organize and become fully functional at different times during childhood. At birth, for example, the brainstem areas responsible for regulating cardiovascular and respiratory function must be intact while the cortical areas responsible for abstract cognition have years before they will be fully-functional.

A frustrated three year old (with a relatively unorganized cortex) will have a difficult time modulating the reactive, brainstem-mediated state of arousal and will scream, kick, bite, throw and hit. However, the older child when frustrated may feel like kicking, biting and spiting, but has 'built in' the capacity to modulate and inhibit those urges. All theoretical frameworks in developmental psychology describe this sequential development of ego-functions and super-ego which are, simply, cortically-mediated, inhibitory capabilities which modulate the more primitive, less mature, reactive impulses of the human brain. Loss of cortical function through any variety of pathological process (e.g., stroke, dementia) results in 'regression' -- simply, a loss of cortical modulation of arousal, impulsivity, motor hyperactivity, and aggressivity -- all mediated by lower portions of the central nervous system (brainstem, midbrain). Conversely, any deprivation of optimal developmental experiences which leads to underdevelopment of cortical, sub-cortical and limbic areas will necessarily result in persistence of primitive, immature behavioral reactivity and, predispose to violent behavior.

Special Topics: Plasticity

The human brain is very plastic - meaning that it is capable of changing in response to patterned, repetitive activation (e.g., reading or hearing a new language, learning a new motor skill such as typing). Recalling, however, that the brain is not just "one" large mass of equivalent tissue - recalling that the brain has a hierarchical and complex organization and that different systems mediate different functions, it stands to reason that not all parts of the brain -once developed - are as easy to modify or change with experience. Simply stated, not all parts of the brain are equally plastic.



Brain Plasticity: The human brain is very plastic - meaning that it is capable of changing in response to patterned, repetitive activation (e.g., reading or hearing a new language, learning a new motor skill such as typing). Recalling, however, that the brain is not just "one" large mass of equivalent tissue - recalling that the brain has a hierarchical and complex organization and that different systems mediate different functions, it stands to reason that not all parts of the brain -once developed - are as easy to modify or change with experience. Simply stated, not all parts of the brain are equally plastic. The plasticity of the cortex is much greater than the plasticity of the brainstem.

The malleability of specific human brain areas is different. The most complex area of the brain - the cortex - is the most plastic. We can modify some cortex-related functions throughout life with minimal "effort." For example, even a 90-year-old person can learn a new phone number. The lower parts of the brain - those mediating core regulatory functions - are not very plastic. And that is for good reason. It would be very destructive for these basic and life-sustaining functions to be easily modified by experience once they were organized. A lesion that kills one million neurons in the cortex can be overcome – people recover language and motor skills following a stroke. A lesion in the brainstem that killed as many cells would result in death.

The degree of brain plasticity is related to two main factors – the stage of development and the area or system of the brain. Once an area of the brain is organized, it is much less responsive to the environment – it is less plastic. For some brain areas such as the cortex, however, significant plasticity remains throughout life, such that experiences can continue to alter, easily, neurophysiological organization and functioning. A critical concept related to memory and brain plasticity is the differential plasticity of various brain systems. Not all parts of the brain are as plastic as others. Once the brain has organized (i.e., after age three), experience-dependent modifications of the regulatory system are much less likely than experience-dependent modifications of cortically-mediated functions such as language development

Special Topics: State Dependent Storage and Recall

As described above, the brain changes in a use-dependent fashion. All parts of the brain can modify their functioning in response to specific patterns of activation -- or to chronic activation. These use-dependent changes in the brain result in changes in cognition (this, of course, is the basis for cognitive learning), emotional functioning (social learning), motor-vestibular functioning (e.g., the ability to write, type, ride a bike) and state-regulation capacity (e.g., resting heart rate). No part of the brain can change without being activated -- you can't teach someone French while they are asleep or teach a child to ride a bike by talking with them.

Mismatch between modality of teaching and the 'receptive' portions of a specific child's brain occur frequently. This is particularly true when considering the learning experiences of the traumatized child -- sitting in a classroom in a persisting state of arousal and anxiety -- or dissociated. In either case, essentially unavailable to process efficiently the complex cognitive information being conveyed by the teacher. This principle, of course, extends to other kinds of 'learning' -- social and emotional. The traumatized child frequently has significant impairment in social and emotional functioning. These capabilities develop in response to experience -- experiences that these children often lack -- or fail at. Indeed, hypervigilant children frequently develop remarkable non-verbal skills in proportion to their verbal skills (street smarts). Indeed, often they over-read (misinterpret) non-verbal cues -- eye contact means threat, a friendly touch is interpreted as an antecedent to seduction and rape -- accurate in the world they came from but now, hopefully, out of context. During development, these children spent so much time in a low-level state of fear (mediated by brainstem and midbrain areas) that they were focusing consistently on non-verbal cues. In our clinic population, children raised in chronically traumatic environments demonstrate a prominent V-P split on IQ testing (n = 108; WISC Verbal = 8.2; WISC Performance = 10.4, Perry, in preparation).

This is consistent with the clinical observations of teachers that these children are really smart but can't learn easily. Often these children are labeled as learning disabled. These difficulties with cognitive organization contribute to a more primitive, less mature style of problem-solving -- with violence often being employed as a "tool".

This principle is critically important in understanding why a traumatized child -- in a persisting state of arousal -- can sit in a classroom and not learn. The brain of this child has different areas activated -- different parts of the brain 'controlling' his functioning. The capacity to internalize new verbal cognitive information depends upon having portions of the frontal and related cortical areas being activated -- which, in turn, requires a state of attentive calm. A state the traumatized child rarely achieves.

Children in a state of fear retrieve information from the world differently than children that feel calm (see Figures). We all are familiar with 'test' anxiety. Imagine what life would be like if all experiences invoked the persisting emotion of anxiety. If a child has information stored in cortical areas but in the specific moment is very fearful, this information is inaccessible. In this regard, cognitively stored information does little good in the life-threatening moment. Simple didactic conflict-resolution models are doomed to fail unless they involve elements of role-playing. Imagine how much you would trust an Army that went through combat training by sitting in classroom -- or the E.R. physician about to run her first code after only leaning how to do that by reading a book. In the midst of most threatening experiences -- situations where violence often takes place -- the 'problem-solving' information in the cortex is not easily accessed. It is of interest to note that information learned in song, rhyme or rap is more easily recalled when in a state of high arousal. This is due, of course, to the fact that this information is stored in a different fashion than traditional verbal cognitive information.

Ages	30 ← 15	15 ← 8	8 ← 3	3 ← 1	1 ← 0
Developmental Stage	**Adult** / **Adolescent**	**Adolescent** / **Child**	**Child** / **Toddler**	**Toddler** / **Infant**	**Infant** / **Newborn**
Primary ***secondary*** **Brain Areas**	**NEOCORTEX** / *Subcortex*	**SUBCORTEX** / *Limbic*	**LIMBIC** / *Midbrain*	**MIDBRAIN** / *Brainstem*	**BRAINSTEM** / *Autonomic*
Cognition	Abstract	Concrete	"Emotional"	Reactive	Reflexive
Mental State	CALM	AROUSAL	ALARM	FEAR	TERROR

When threatened, a child is likely to act in an 'immature' fashion. Regression, a 'retreat' to a less mature style of functioning and behavior, is commonly observed in all of us when we are physically ill, sleep-deprived, hungry, fatigued or threatened. As we 'regress', in response to the real or perceived threat, our behaviors are mediated (primarily) by less-complex brain areas. If a child has been raised in an environment of persisting threat, the child will have an altered baseline such that the internal state of calm is rarely obtained (or only artificially obtained via EtOH or drugs). In addition, the traumatized child will have a 'sensitized' alarm response, over-reading verbal and non-verbal cues as threatening. This increased reactivity will result in dramatic changes in behavior in the face of seemingly minor provocative cues. All too often, this over-reading of threat will lead to a 'fight' or 'flight' reaction -- and impulsive violence. The child will view their violent actions as defensive.

Children exposed to significant threat will "re-set" their baseline state of arousal such that even at baseline -- when no external threats or demands are present, they will be in a physiological state of persisting alarm. As external stressors are introduced (e.g., a complicated task at school, a disagreement with a peer) the traumatized child will be more 'reactive' -- moving into a state of fear or terror in the presence of even minor stressors. The cognition and behavior of the child will reflect their state of arousal. This increased baseline level of arousal and increased reactivity in response to a perceived threat plays a major role in the associated behavioral and cognitive problems associated with traumatized children.

Key Points: Brain Organization and Function

- The brain is not a 'single' system. It is many interacting and interconnected systems organized in a specific hierarchy -- with the most complex (cortex) on the top and the least complex (brainstem) on the bottom.
- Different parts of the brain -- different 'systems' in the brain' -- mediate different functions (e.g., the cortex mediates thinking; the brainstem mediates state of arousal).
- All systems in the brain are comprised of networks of nerve cells (neurons). These neurons are continuously 'changing' (in chemical and structural ways) in response to 'signals' from other parts of the brain, the body or the environment (e.g., sight, sound, taste, smell).
- These molecular, chemical 'changes' in neurons allow the storage of 'information'. This storage of information is the basis for 'memory' -- memory of all types -- motor, sensory, cognitive and affective.
- Different parts of the brain -- which mediate different functions -- store information (memory) that is specific to the function of that part of the brain. This allows for different types of 'memory' -- for example, cognitive (names, phone numbers), motor (typing, riding a bicycle), and 'affect' (nostalgia).
- The brain stores information in a use-dependent fashion. The more a neurobiological system is 'activated' the more that state (and functions associated with that state) will be 'built' in -- for example, practicing the piano, 'memorizing' a poem, or staying in a state of fear.
- In different 'states' of arousal (e.g., calm, fear, sleep), different neural systems are activated. Because the brain stores information in a use-dependent fashion, the information 'stored' (i.e., the memories) in any given situation depends upon the state of arousal (i.e., the neural systems that are activated). One example of this is 'state-dependent' learning -- another is the hyperarousal symptoms seen in post-traumatic stress disorder.

Glossary

Action potential: This is an electrical charge that travels down the axon of a neuron to the synaptic terminal where it can increase or decrease the probability that hundreds of intracellular vesicles filled with neurotransmitter will fuse with the pre-synaptic membrane of that neuron and release the neurotransmitter into the synaptic cleft. The action potential occurs when the neuron has been activated and temporarily reverses the electric polarity of the interior membrane from negative to positive.

Amygdala: This is a structure in the forebrain. It is part of the limbic system and plays a major role in emotional memory and the response to threat.

Axon: This is the tiny fibrous extension of the neuron away from the cell body to other target cells (neurons, muscles, glands).

Autonomic Nervous System: The ANS is that part of the nervous system responsible for regulating the activity of the body's other organs (e.g., skin, muscle, circulatory, digestive, endocrine).

Central Nervous System: This is the portion of the nervous system comprised of the spinal cord and brain.

Cerebellum: This is a large cauliflower-looking structure on the top of the brainstem. This structure is very important in motor movement and motor-vestibular memory and learning.

Cerebral Cortex: This is the outer most layer of the cerebral hemispheres of the brain. The cortex mediates all conscious activity including planning, problem solving, language and speech. It is also involved in perception and voluntary motor activity.

Cognition: This refers to the mental process by which we become aware of the world and use that information to problem solve and make sense out of the world. It is somewhat oversimplified but cognition refers to thinking and all of the mental processes related to thinking.

Glia: These are specialized cells that nourish, support and complement the activity of neurons in the brain. Actrocytes are the most common and appear to play a key role in regulating the amount of neurotransmitter in the synapse by taking up excess neurotransmitter. Oligodendrocytes are those glia that specialize to form the myelin sheath around many axonal projections.

Hippocampus: This is a thin structure in the subcortex shaped like a seahorse. It is an important part of the limbic systems and plays a major role in learning, memory and emotional regulation.

Homeostasis: This is the tendency of a physiological system (i.e., a neuron, neural system or the body as a whole) to maintain its internal environment in a stable equilibrium

Hypothalamus: This is a group of important nuclei that mediate many important functions. It is located at the base of the brain and connected to the pituitary by a network of specialized blood vessels. The hypothalamic nuclei are involved in regulating many of the body's internal organs via hormonal communication. The hypothalamus is a key part of the hypothalamic-pituitary-adrenal (HPA) axis that is so important in the stress response.

Limbic System: This is a group of functionally and developmentally linked structures in the brain (including the amygdala, cingulate cortex, hippocampus, septum and basal ganglia). The limbic system is involved in regulation of emotion, memory and processing complex socio-emotional communication.

Neuron: A cell specialized for receiving and transmitting information. While neurons have tremendous heterogeniety in structure, they all have some form of dendritic projections that receive incoming information and axonal projections that communicate to other cells.

Neurotransmitter: A chemical that is release from a neuron that can relay information to another cell by binding to a receptor on the membrane of the target cell.

Plasticity: This refers to the remarkable capacity of the brain to change its molecular, microarchitectural and functional organization in response to injury or experience.

Synapse: This is the specialized space between two neurons that is involved in information transfer. Neurotransmitter is released from one neuron enters the synaptic cleft (space) and sends a 'signal' to the post-synaptic neuron by occupying that receptor's receptors.

Thalamus: This is a paired structure of two tiny egg-shaped structures in the diencephalon. This structure is a crucial area for integrating and organizing sensory information that comes into the brain. In the thalamus, this information is processed and forwarded to the key cortical areas where more processing and integrating will take place.

Use-dependent: This refers to the specific changes in neurons and neural systems following activation. Repetitive, patterned stimulation alters the organization and functioning of neurons and neural systems and, thereby, the brain.

Resources

There are hundreds of places to learn more about the brain. A few useful starting places are listed below.

Books: Professional or Reference

Coffee, CE and Brumback, RA, (Eds)_**Textbook of Pediatric Neuropsychiatry** American Psychiatric Press, Inc. Washington, (1998)

This compiled textbook has a host of useful chapters about brain structure and organization presented from a clinical perspective. This may be a very useful resource to any professional working with children suffering from neuropsychiatric symptoms. While it is focused on neuropathology, there are several excellent chapters on neurophysiology.

Cooper, J.R., Bloom, F.E. and Roth, R. H. **The Biochemical Basis of Neuropharmacology** Seventh Edition Oxford University Press (1996):

This is an excellent book by some of the most respected neuroscientists in the United States. It is at the level of an educated biology college student with lots of technical language but it is an invaluable book for anyone interested in the brain. It has many useful references and great figures to illustrate key points about neurotransmission and how neural systems work.

Kandel, E.R., Schwartz, J.H. and Jessell, T.M. **Principles of Neural Science**: Third Edition Appleton & Lange, Norwalk, CT (1991)

This is the most comprehensive and useful textbook about the neurosciences that exists. This is well-written and well-referenced. It is a must for anyone interested in the brain. It is relatively expensive but it is the best place to start for almost any brain-related topic.

Maclean, P.D. **The Triune Brain in Evolution: Role in Paleocerebral Functions** Plenum Press, New York and London (1990)

Paul Maclean is a genius. He is one of the most original and thoughtful scholars in the neurosciences over the last fifty years. He is responsible for our current understanding of the limbic system. This book is actually for people with some background in the neurosciences but might still be of interest to a self-motivated lay reader.

Books: General Readers

Diamond, M. and Hopson, J. **Magic Trees of the Mind: How to Nurture Your Child's Intelligence, Creativity and Healthy Emotions from Birth Through Adolescence** Dutton, New York, NY (1998)

This book is a thoughtful review of much of the work on enriched environments and brain development. Dr. Diamond is a pioneer in these studies. The most fascinating elements of this book include the sections examining the work that has been done on enriched environments for human children. This book has practical suggestions for parents and a very good resource section. This book is targeting the general population.

Gopnik, A., Meltzoff, A.N. and Kuhl, P. **The Scientist in the Crib: Minds, Brains and How Children Learn** William Morrow and Company, New York (1999)

This is a new book by a team of respected neuroscientists who have been studying the development of language in babies. This group writes a very well-referenced and thoughtful book about the value of early childhood experience in cognitive and emotional development. There is actually little about brain structure, organization or development but lots about principles of brain functioning. This is appropriate for general readership.

Kotulak, R. **Inside the Brain: Revolutionary Discoveries of How the Mind Works** Andrews and McMeel, Kansas City, MO (1996)

This is a book by a Pulitzer-prize winning science writer. He reviews some of the emerging findings in the pre-clinical neurosciences with a focus on mental health, violence and aggression, substance abuse and other neuropsychiatric disorders. This is a very readable book and is a good start for anyone interested in learning about the brain.

Other Resources

The Human Brain: A Mystery to Itself

This award winning interactive site is an excellent introduction to brain structure and organization.

http://library.advanced.org/26463/

The Human Brain: Dissections of the Real Brain

You really want to see what the brain looks like? This site has a well-presented dissection of the human brain. It is a useful way to see what these areas really look like. Visit this site and admire the work of Terence H. Williams, M.D., Ph.D., D.Sc.. Nedzad Gluhbegovic, M.D., Ph.D. and Jean Y. Jew, M.D.

http://www.vh.org/Providers/Textbooks/BrainAnatomy/BrainAnatomy.html

Society for Neuroscience

The Society for Neuroscience is the world's largest organization of scientists and physicians dedicated to understanding the brain, spinal cord and peripheral nervous system. This site has a number of very useful materials for professionals without specific expertise in the neurosciences. The educational programs and materials are well written, clear and accurate; overall an excellent resource.

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About the Society

These resources will be periodically updated and posted in a special section of the ChildTrauma Academy web site http://www.ChildTrauma.org. Visit this site for updates and for other resource materials about traumatic events and children.

About the Author

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Dr. Perry is the Senior Fellow of the ChildTrauma Academy. In addition he serves as the Medical Director for Children's Mental Health Services for the Alberta Mental Health Board. From 1992 to 2001, Dr. Perry served as the Thomas S. Trammell Research Professor of Child Psychiatry at Baylor College of Medicine and Chief of Psychiatry at Texas Children's Hospital in Houston, Texas.

The ChildTrauma Academy

The ChildTrauma Academy, a not-for-profit organization based in Houston, TX, is a unique collaborative of individuals and organizations working to improve the lives of high-risk children through direct service, research and education. These efforts are in partnership with the public and private systems that are mandated to protect, heal and educate children. The work of the Academy has been supported, in part, by grants from Texas Department of Protective and Regulatory Services, the Children's Justice Act, the Court Improvement Act and through innovative partnerships with academic and corporate partners such as Powered, Inc., Scholastic, Inc., Linkletter Films and Digital Consulting and Software Services.

The mission of the ChildTrauma Academy is to foster the creation of innovations in practice, programs and policy related to traumatized and maltreated children. To support this mission, the Academy has two main activities; 1) Program development and consultation and 2) Specialized education and training services.

For more information or to direct donations:

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Web Resources:

ChildTrauma Web site
www.ChildTrauma.org