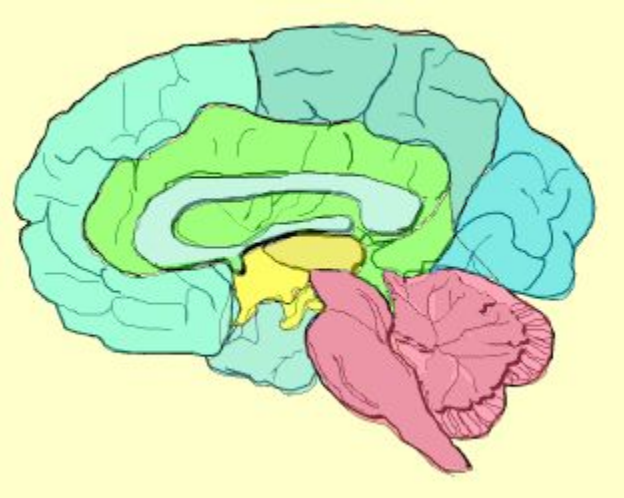
Brain Structure and Function I:

Basics of Organization



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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 traumdatized 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

The adult brain weighs about three pounds. This three pounds of, primarily, water and fat, allows us to walk and talk; to laugh, cry and touch; to love, hate, create or destroy. Everything we do, everything we think, everything we feel, every wish, dream, regret and hope is mediated by our brain. Our brain guides us through our lives. By sensing the world around us, storing some fragment of each unique moment, cataloguing, sorting, organizing and acting on our experiences, our brain defines us. It is the brain that allows us to be connected to each other in the present. It is the brain that links us to the past as our language, religion, economies, technologies – essentially all of our cultural practices - reflect the distilled experiences of thousands of generations of our ancestors. And it is the brain that connects us to the future as we pass elements of our life experience to the next generations. It is the brain that allowed humankind to create humanity.

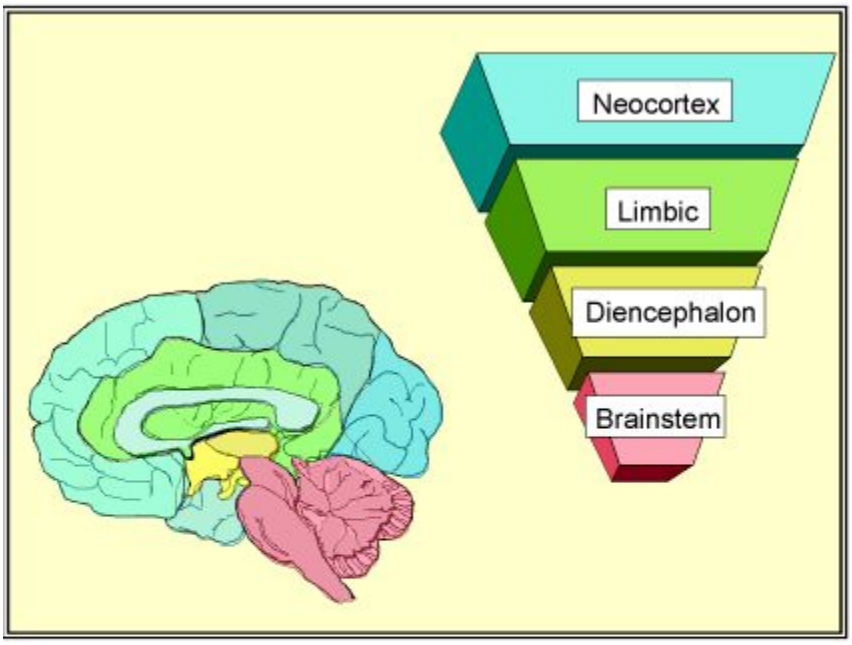
The purpose of this booklet is to provide background information about the brain's structure and function that create the framework for understanding the impact that maltreatment or trauma may have on the developing child. The majority of professionals working with maltreated children do not have a background 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.

The Brain's Prime Directive

Sharks sense blood in water, dogs hear very high pitched sounds, bears detect scents from miles away, geese navigate thousand mile migrations somehow sensing magnetic fields of the earth, hawks see the movement of prey from hundreds of feet in the air and snakes "sense" body heat. Each of these unique capabilities is mediated by the animal's brain. Their brain's capacities to sense, process and act are designed to help keep them alive – to find food, to avoid threat, to procreate and keep the species going. It is, in many regards, the same for us. We need a brain to keep our species going. Without the unique properties of the brain, humankind would have long ago become extinct. Our brain helps keep us alive and thriving while we develop. And then, once mature, our brain allows us to create, protect, nurture and teach the next generation. Our brain is designed to help us survive, procreate and become caregivers.

The brains of the animals described above have sensory and brain-mediated capabilities that are specialized for the challenges and threats of the ecosystems in which they evolved – the climates, predators, prey, and geography that thousands of generations of their species faced. Again, it is the same for us. Our brain has special capabilities that helped promote survival in the environmental conditions – the ecosystems and social systems – facing thousands of generations of our human and pre-human ancestors. This is important. This means that the human brain, our brains,

have structural and functional capabilities that were selected to promote survival in "primitive" hunter-gatherer bands of about forty people. For 99 percent of the time we have been homo sapiens sapiens, our ancestors lived in these small groups where their lives were characterized by nomadic migration, cooperative hunting of large game and foraging for non-cultivated fruits and grains. The social structures, economies, communications, technologies and manifestations of abstract creativity that now characterize human life were not present when the human brain was evolving. In many ways, the complexities of the modern world (a distilled reflection of the creativity of thousands of human brains) pose tremendous and unfamiliar challenges to a human brain designed for a different world.



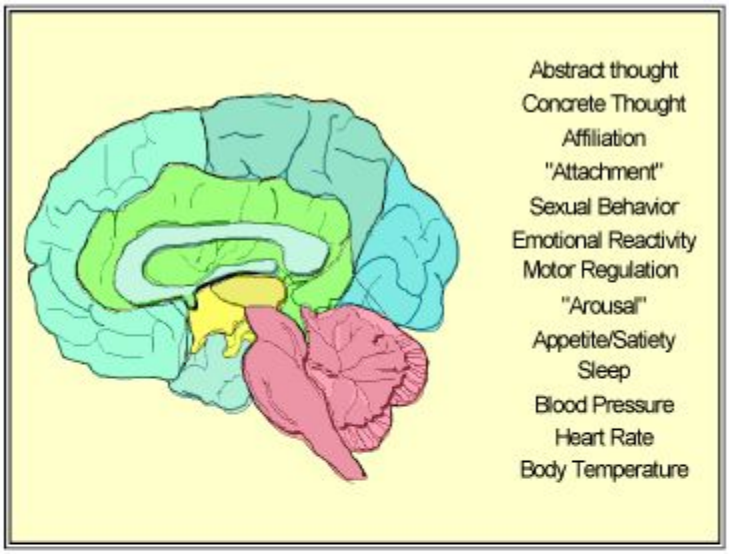
The Human Brain: The brain can be divided into four interconnected areas: brainstem, diencephalons, limbic and neocortex. The complexity of structure, cellular organization and function increases from the lower, most simple area, the brainstem to the most complex, the neocortex.

It is in these historical roots that the brain's key capabilities were evolved, modified and refined to allow the survival of the species. The key elements of brain functioning work together to ensure that the three prime directives of the human brain allow the survival of the species. It is our brain that ensures that we survive, we mate and procreate and we protect and prepare the young. Without the brain-mediated capabilities to do any of these, our species could not have survived.

The Brain's Key Actions

Despite its complexity, the brain has some key actions. The brain senses, processes incoming signals, stores elements of this information and acts on the incoming input.

Sense: In order to keep us alive, the brain has a set of sensory organs (eyes, ears, nose, taste, touch) to tell us some of what is going on in the outside world. Remember, we can't hear like a dog, smell like a bear or see like a hawk. Our ears hear sound within a certain range, we see "light" in the visual range not infrared or ultraviolet, the perception of touch requires a certain level of pressure, we smell only when the scent is powerful or close. But, with the senses we have, our brain can integrate the information from these different senses and create an internal representation of the external world.



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.

All experience is filtered by our senses. All sensory signals (e.g., sound, sight, taste, touch), in turn, initiate a cascade of cellular and molecular processes in the brain that alter neuronal neurochemistry, cytoarchitecture and, ultimately, brain structure and function. This process of creating some internal representation of the external world (i.e., information) depends upon the pattern, intensity and frequency of neuronal activity produced by *sensing, processing and storing* signals.

The more frequently a certain pattern of neural activation occurs, the more indelible the internal representation- the more indelible the 'memory.' Experience thus creates a processing template through which all new input is filtered. All living organisms have mechanisms to sense and respond to changes in their environments. These environments – external as 'sensed' by our five senses and internal as 'sensed' by a set of specialized neurons throughout the body (e.g., glucose or sodium sensitive neurons) – are always changing. A continuous, dynamic process of modulation, regulation, compensation and activation characterizes our neurophysiology

– all designed to keep our body's systems in some state of equilibrium or homeostasis. Each of our many complex physiological systems has a rhythm of activity that regulates key functions; when blood sugar falls below a certain level, a set of compensatory physiological actions are activated. When tissue oxygen is low from exertion, when an individual is dehydrated, sleepy or threatened by a predator, still other regulating activities will be turned on to respond to the specific need. For each of these systems there are 'basal' or homeostatic patterns of activity within which the majority of environmental challenges can be sustained.

We have other sensory mechanisms to tell the brain what is going on in the internal world – the physiological milieu of the body. For example, we have special sensory apparatus that tell the brain the concentration of oxygen in the blood; others sense the concentration of salts (too high and we become thirsty), or gases such as CO2. These internal sensory apparatus, like the five senses for the external world, help the brain continuously monitor and act to keep us alive.

Process: Once our sensory apparatus has translated physical or chemical information from the outside (or inside) world into neuronal activity, this set of signals travels up into the brain to be processed. Sensory information from the external environment (visual, auditory, tactile, olfactory, gustatory) and the internal environment (e.g., blood glucose, arterial pressure, CO2 levels) enters the central nervous system at the level of the brain stem and midbrain. As this primary sensory input comes into the brain stem and midbrain, it is matched against previously stored patterns of activation and if unknown, or if associated with previous threat, the brain will activate a set of responses that are designed to help promote survival. This alarm response is at the heart of the post-traumatic symptoms seen in so many maltreated children (see other Academy booklets).

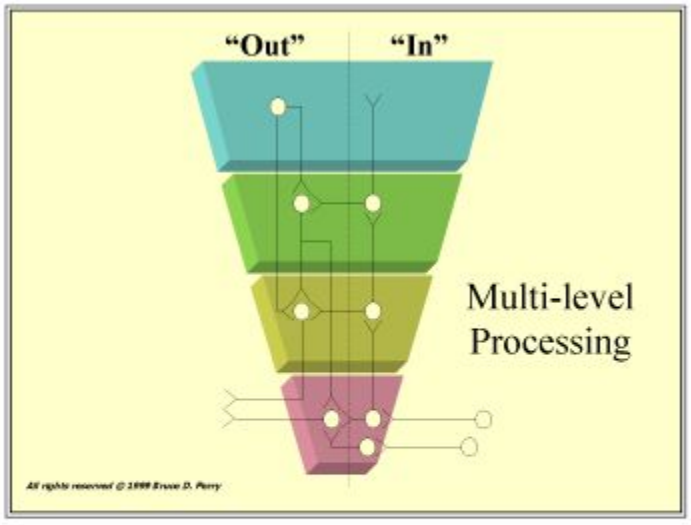
Throughout life, the brain is sensing, processing and storing patterns of neuronal activation (i.e., making memories) that correspond to various sights, sounds, smells, tastes, movements. Using various modes of memory (e.g., cognitive, emotional, motor) the brain stores these patterns, making associations between the multiple sensory stimuli that co-occur, creating templates of experience against which all future experience is matched.

In this regard, the brain is a conservative organ. It does not like to be surprised. All unknown or unfamiliar environmental cues are judged to be 'threatening' until proven otherwise. Novel stimuli focus attention, increase arousal and induce an alarm response until they can be proven neutral or safe. New patterns and cues that do not match the stored 'memories' of previous experience prime the stress-response systems in the brain. Once categorized as neutral, safe or threatening, these stored 'memories' are added to the catalogue of patterns, cues and associations against which subsequent environmental cues are matched.

What is safe and comfortable becomes so through experience; something in the present moment matches the associated, stored 'memories' of previous safe, pleasing or

rewarding experiences. In contrast, when the environment, internal or external, matches with stored neuronal patterns associated with a previous threatening experience, the brain's stress- response systems will be activated. Key signs and symptoms of trauma-related neuropsychiatric disorders result from these memories of 'fear' – storing elements of traumatic experience, making associations, generalizing and, later, triggering complex, multi-system responses (i.e., cognitive, emotional, motor, 'state') reflecting these 'memories'. This process of creating memories of fear occurs at multiple levels in the brain's hierarchical systems.

As the neural signals from primary sensory systems (i.e., vision, hearing, taste, touch, smell) come into the brainstem, a process of integrating the signals starts. At each level of the brain, further integration takes place so that by the time the signals from an event reach the thalamic nuclei, there has been an integration that allows a more complex "internal" representation. Sensory integration – putting the sight, sound, smell and feel of an event together – is a crucial step in healthy development. There can be disruption of this capacity by even minor timing errors. If the signals coming from the neural systems responsible for hearing do not get into the thalamus and cortex in a synchronous way, there can be confusion, disorganization and abnormal functions. A tiny glimpse into this dysynchrony can be illustrated by the feeling you get when you watch a poorly dubbed foreign film – or if you watch TV with a tiny sound delay. The movements don't match with the sound – it is disorienting. Again, this can happen with fear alters the processing of incoming information – time seems suspended, sounds fade or accentuate, movement can seem in slow motion (anyone who has driven on ice and watched as their car slips towards someone else's bumper knows this feeling).



Sequential Processing All incoming sensory information first enters the CNS at the level of the spinal cord or brainstem. This means that the first place where patterns of activation are matched against previously stored templates is in these primitive areas. Indeed, the spinal cord and brainstem may process and act on incoming information before the integrated and interpreted signals even get up to the cortex (e.g., reflex withdrawal of a finger from fire).

At each level of brain organization, the incoming afferent signal is categorized. By comparing the incoming signal with previously stored patterns, the brain can help categorize the incoming information. Sometimes this results in mistakes. For the Vietnam Vet, a loud firecracker can induce a startle response and anxiety even though he knows it is only a firecracker. That is because the incoming loud sound is categorized in the brainstem as being previously associated with threat and danger – and there is an immediate response – even before the signal can get to the cortex. At each level of processing that takes place, there is

a categorization process. This immediate, localized processing and acting can be crucial for survival. Your brainstem and spinal cord will tell you to withdraw your hand from a fire even before your cortex knows that you have been burned.

Another key step in processing experience is in organizing information. Because the brain cannot possibly create a unique neural imprint or pattern of change to store every element of every experience, the brain stores ‘template’ patterns based upon the first set of organizing experiences. All future incoming input is matched against these stored templates and, if sufficiently different from the original pattern, the brain will make neural changes (i.e., create a memory) that reflects that tiny difference. Take the visual image of mother’s face. To the infant, if no other face has ever been seen, the infant’s brain will create some neural templates the basic features of a face – eyes, nose, mouth, expressions. And when baby first sees father – the neural templates for face are in place – only minor modifications need be stored.

Store: Inherent in the processing of information coming into the brain is the capacity to store elements of these incoming signals. At the heart of our survival neurobiology is the capacity to make and store internal representations of the external world – memory. The ability of the brain to create memories is due to the capacity of neurons and neural systems to change from one ‘homeostatic’ state to another. In response to a set of stimuli-induced (e.g., sensations) alterations in activity, neurons undergo molecular changes that reflect this activity. In a very real sense, unless the homeostatic dynamic of a neural system is altered by "use", it will not change – it will not make internal representations of the experience – it will not make memories. Neurons and neural systems change in a "use-dependent" fashion. Therefore, when neural systems that have their homeostatic patterns of activation influenced by new or extreme patterns corresponding to new or extreme environmental situations, they will change their molecular neurophysiology, creating "memories."

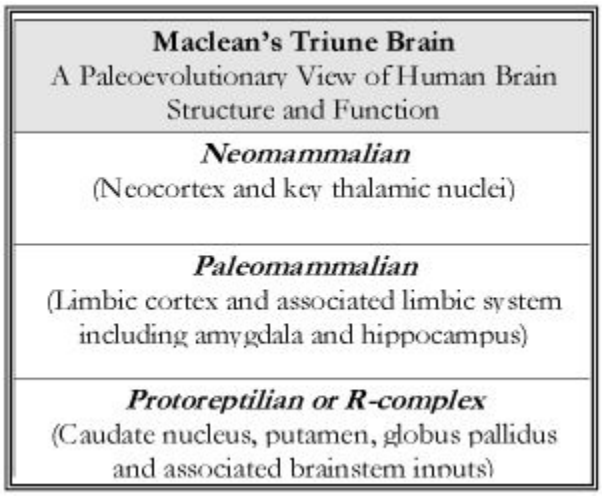
This has important implications for understanding how we ‘create’ memories of traumatic experiences. For adults, most experiences have only a small component that is ‘new’ or unique. Typically, the majority of places, faces, words, sounds, smells, tastes in any given moment are familiar – the brain has sensed, processed and stored these patterns before. In these situations only some portions of the brain are ‘activated’ and processing outside of their homeostatic range. In the classroom, for example, a lecture may result in cortical activation but will cause little new emotional, motor or arousal activity. The result, hopefully, is new cognitive memories – storing the information from the lecture. Similarly, practicing piano may result in new cerebellar-basal ganglia-motor cortex activity and create ‘motor’ memories but have little effect on emotional or state-regulation areas of the brain.

Act: Finally, the brain mediates and controls the actions of the human body. By regulating and directing the actions of the neuromuscular, autonomic, endocrine and immune systems the brain controls the actions of the human being. The neuronal pathways sending signals into a brain area are called afferent and those sending signals out are called efferent. The efferent pathways regulate the actions resulting from

the process of sensing, processing and storage of incoming signals. Now this simple (and somewhat misleading) linear process is only a crude approximation of the key actions of the brain. Indeed, there are hundreds if not thousands of local and regional feedback loops in an open and interactive dynamic system (well beyond any mathematical models of complex systems yet developed).

Brain Organization and Function

In order to do all of these key actions, the brain has evolved a wonderful and highly functional structure. The brain is not just one homogeneous mass of tissue. The brain has a complex and hierarchical organization. Multiple parallel systems exist that mediate various distinct functions. In general, the complexity of brain structure and the functions that these different structures mediate are organized in a bottom to top organization (see Figure 1).



The bottom line is that the brain has lots of parts. For our purposes, the brain will be divided into four major areas: brainstem, diencephalon, limbic and neocortical. This, of course, is not the only way to divide up the brain. The organization of the brain can be described from several perspectives. This is not surprising considering how complex it is. Several ways to think about the organization of the brain are listed below.

One common and important way to think about brain organization is to literally look at it. There are two major approaches to "looking" at the brain; what is visible to the un-aided eye (gross anatomy) and what is visible when using magnifying aids (neurohistology). The combination of the different areas determined from neurohistology and from neuroanatomy has defined many constituent parts of the brain (see table below). From these constituent parts, certain larger regions can be defined. In one of the most original and useful ways of understanding the human brain, Paul Maclean, a pioneer of modern neuroscience, has defined three distinct systems within the brain that correspond to key evolutionary systems that have evolved across various species. This Triune Brain model defines the lower, less complex areas of the brain as being similar in structure and function to the reptilian brain – hence his term the R-complex. Maclean identifies the limbic and associated areas as the paleomammalian system. Finally, the neomammalian systems are those that are in the neocortex and associated sensory integration nuclei in the thalamus. These areas are uniquely organized in primates. In other Academy booklets examining the impact of abuse, neglect or trauma on the brain, we will return to this useful model.

The more common approaches to division of the human brain are outlined in the table below. In the most simple, there are three division: hindbrain, midbrain and forebrain. The developmental style of dividing is based upon the developmental heritage of the given constituent parts. The four part division used in this booklet is on the left hand column.

The key observation in organizational process is that the brain has a hierarchical organization, from bottom to top, becoming more complex. The most complex part of the brain is he cortex when 50% of all neurons in the brain are within the outer ¼ inch of the surface of the cortex. When examining genetic homology across species, the frontal cortex (part of the neocortex) is the most "uniquely" human with only about 94 % homology with non-human primates while other cortical areas are 96 to 98 % homologous. It should be no surprise then that the most unique human properties are mediated by the cortex, especially, the frontal cortex.

Matching the hierarchical structure is a hierarchy of function. The simplest regulatory functions are mediated by the lower brainstem areas and the most complex by the neocortex (see figures above). The key to remember is that different brain areas and systems mediate different functions. This will be important when trying to understand the changes in emotional, behavioral and cognitive functioning that take place when someone is threatened.

Functional Division	Constituent Parts	Developmental Division	Primary Division	
Neocortex	**Cerebral cortex** Frontal Lobes Temporal Lobes Parietal Lobes Occipital Lobes Corpus Callosum	Telencephalon	Cerebral Hemispheres	Forebrain
Limbic Cingulate Cortex Amygdala Hippocampus Septum	Amygdala			
	Hippocampus			
	Basal ganglia Caudate Nucleus Putamen Globus Pallidus			
Diencephalon	Thalamus	Diencephalon	Diencephalon	
	Hypothalamus			
Brainstem	**Midbrain** Superior Colliculus Inferior Colliculus	Mesencephalon	Brainstem	Midbrain
	Cerebellum	Metencephalon		Hindbrain
	Pons			
	Medulla Oblongata	Myelencephalon		
Spinal Cord	Spinal Cord		Spinal Cord	

The Brain's Building Blocks

The brain is an amazingly complex organ. Indeed, it is the most complex biological organ in the known universe. It is comprised of trillions of "moving parts" – the cells of the nervous system.

Neurons: The basic structural units of the human brain are cells. The brain is comprised of two major types of specialized cells, neurons and glial cells. Each cell has a cell wall, a membrane the separates the inside (intracellular) components of the cell from the outside (extracellular) environment of the cell (Fig. X). Inside each of these 100 billion neurons and 1 trillion glial cells is the exact same genetic material, the same genes. Yet, each of these 1.1 trillion cells is expressing only a portion of this genetic material. More astounding, each of these cells is expressing a unique pattern of gene activation that is a reflection of the cell's history and current environment.

The Neuron: Neurons come in a variety of shapes and sizes. Most of them have a long process called an axon (right half of figure) that conducts information away from the neuronal cell body (soma) and a series of smaller processes called dendrites (left half) that receive information from other nerve cells through synaptic connections (synapses). The vast majority of human neurons are multipolar; that is, there are multiple dendritic projections from the cell body and almost always an axon as well.

Neurons are cells specialized to receive, store and transmit information – the business of neurons is communication. All neurons have special structural features that allow neurons to 'communicate' - to receive, process, store and send 'information' that comes from their outside (extracellular) world (sound familiar?). Specialized structural and biochemical properties allow to receive a stream of chemical signals from other neurons, process these incoming 'messages', change their chemical interior in response to these signals (and thereby, store important 'information'), and then transmit the summed signals to other neurons. Chains of neurons embraced in continuous dialogue, continuous communication, create functional systems that allow the brain to mediate and control a host of remarkable activities.

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There are hundreds of "types" of neurons. They can be classified by unique structural properties or by unique functional properties. Neurons that are directly involved in the transduction of physical or chemical signals from sense organs are called sensory neurons. Sensory neurons are either directly sensitive to various stimuli (i.e. touch or temperature changes) or else receives direct connections from non-neuronal receptor cells. Motor neurons end directly on muscles or glands. Interneurons interconnect other neurons. For the most part, the CNS is composed almost entirely of interneurons. In some areas of the brain, neurons are densely packed while in others they are distant. Most neurons form their connections with neighboring neurons that are physically adjacent. Through short axonal connections, these "intrinsic" neurons interact with and modify brain activity in their local areas. Other neurons, however, send axons to other neurons in distant areas of the brain. These are called extrinsic neurons. Extrinsic neurons tend to form groups or clusters called nuclei. The nucleus of cells then sends a group of axonal connections to various distant brain areas. One extrinsic neuron may send axonal projections to several widely separate brain areas. The fact that one neuron or one group of neurons can send simultaneous signals to many areas suggests that these nuclei will play important roles in orchestrating and coordination of communication and functioning of the brain.

Glial Cells: Glia get a bad rap. Despite being 90% of the cells in the brain, we don't have the gliosciences or gliologists – we have the neurosciences and neurologists. Make no mistake, neurons are the major functional cells in cross-regional communication. Recent studies suggest that glial cells also play an important role in communication. Many glial cells have receptors for neurotransmitters and may play a role in the co-release of various classical and non-classical neurotransmitters or neuromodulators.

The major functions of glial cells, however, appear to be "supportive" of the communication functions of neurons. To do so, there are several types of glial cells in the CNS. Some of them (oligodendroglia in the CNS and Schwann Cells in the periphery) form myelin sheaths, which are fat wrappings –like insulation - around axons that allow the axons to conduct information more rapidly. Other types of glial cells regulate the composition of extracellular fluids, complement neurons in certain metabolic activities, and participate in various humoral functions within the CNS. Glial cells provide crucial 'support' functions for neurons (e.g., guiding developing neurons to the 'right' places in the brain, storing extra energy for active neurons).

Neuronal Communication: Creating Neuronal Networks

Synaptic transmission: Neurons and glial cells are the 'building blocks' of brain structure, while neuron-to-neuron communication is the basic unit of brain function. It is quite astonishing to think that, somehow, the memory of a loved one's face or the capacity to create a new loving bond with another person is created by some dynamic pattern of synaptic activation. Yet, based upon what is known about brain functioning, this must be the case. We have so much yet to learn, but one essential element of this process is neuron to neuron communication. synaptic transmission.

The Synapse: The neurotransmitter is stored in the vesicles, which will fuse with the pre-synaptic neuron's membrane and release the neurotransmitter into the synaptic cleft. The neurotransmitter diffuses across this space and occupies receptors on the post-synaptic neuron, initiating a cascade of chemical communication central to all nervous tissue functioning.

The major biochemical mechanism for this neuron to neuron communication is 'receptor-mediated' synaptic neurotransmission at unique areas of where neurons come in close proximity. These areas of close proximity are called synapses. In the synapse, the distance between neurons is very short. A chemical (classified as a neurotransmitter or neuromodulator) is released from one neuron makes its way across an extra-cellular space and binds to a specialized protein called a receptor. By occupying the binding site, the neurotransmitter helps change the shape of this receptor which helps it then catalyze a secondary set of chemical interactions INSIDE the neuron that create second messengers. The second messengers such as cyclic AMP, inositol phosphate and calcium will then shift the intracellular dynamic of other chemicals which may even influence the activity of specific genes. This cascade of intracellular chemical responses can then influence the activity of that cell and may change the rate of firing – hence the rate of release of neurotransmitter.

A continuous dynamic of synaptic neurotransmission regulates the activity and functional properties of the chains of neuronal systems that allows the brain to do all of its remarkable activities.

Final Comments

The brain and its constituent parts are the most complex system in the known universe. With one trillion separate cells, each one in a continuous process of changing in response to chemical signals. From the moment of conception to the moment of death, the biology of the individual is changing. The greatest changes take place in the brain. Each of its trillion cells has the very same genes – the very same genetic potential. Yet, through the long process of development, the history of each cell's progenitors and its individual history of micro-environmental history (i.e., the timing, pattern, quality and nature of activation) have determined that at any given moment only a fraction of the genome is expressed. Each cell is expressing a different combination of the genome. Each cell is unique. Some cells become glia, some neurons. Some neurons (noradrenergic) use norepinephrine as a neurotransmitter, some serotonin. Some noradrenergic neurons are in the locus coeruleus, some are in the pons. Some locus coeruleus noradrenergic neurons project to the hippocampus, others to the cortex and amygdala. And on and on.

It is in this complexity that our species has found the capability to store the accumulated experience of thousands of generations – to create human culture. Our language, religions, governments, childrearing practices, technologies, economies – are all man-made; yet all depend upon the remarkable capacity of the brain to make internal representations of the external world. It is the amazing plasticity and malleability of the human brain that allows humanity.

Appendix 1: Maybe More Than You Really Wanted to Know

The following is a more detailed description of some of the organizational and functional features of key brain regions. The reader should note that this division is an anatomical and not a functional division. The limbic systems articulated in Maclean's triune brain model includes some structures in the cerebral cortex (e.g., cingulate cortex, hippocampus) and some structures in the diencephalon (e.g., key thalamic nuclei). This appendix presents brain structure from a more traditional neuroanatomical perspective.

Cerebral Cortex

This part of the brain is divided into four sections. 1. Occipital Lobe; 2. Temporal Lobe; 3. Parietal Lobe; and 4. Frontal Lobe. Functions such as hearing, vision, speech, and executive function are associated with these regions. Major internal structures of the cerebral cortex include the *forebrain* that is credited with the highest intellectual functions of thinking, planning, and problem solving. The *hippocampus* is involved more directly in memory formation and retrieval. The *thalamus* serves as a relay station for virtually all the information coming into the brain. Neurons in the *hypothalamus* serve as relay stations for internal regulatory systems; they monitor information coming in from the autonomic nervous system and directing the body through those nerves and the pituitary.

Cerebral Lobes: Four prominent sulci – the central sulcus, the lateral sulcus, the parieto-occipital sulcus, and part of the calcarine sulcus – and the preoccipital notch are used to divide each cerebral hemisphere into four lobes.

1. The frontal lobe extends from the anterior tip of the brain to the central sulcus. Inferiorly it ends at the lateral sulcus while on the medial surface, it extends posteriorly from the top of the central sulcus to the corpus callosum.
2. The parietal lobe extends from the central sulcus to an imaginary line from the top of the parieto-occipital sulcus to the pre-occipital notch. Inferiorly, the lateral fissure and the imaginary continuation of this fissure bound it to the posterior boundary of the parietal lobe. On the medial surface of the brain, it is bounded inferiorly by the corpus callosum and calcarine sulcus, anteriorly by the frontal lobe, and posteriorly by the parieto-occipital sulcus.

3. The temporal lobe extends superiorly to the lateral sulcus and the line forming the inferior boundary of the parietal lobe; posteriorly it extends to the line connecting the top of the parieto-occipital sulcus and the preoccipital notch to the splenum of the corpus callosum.
4. The occipital lobe is bounded anteriorly by the parietal and temporal lobes on both the lateral and medial surfaces of the hemisphere.

An additional area of cerebral cortex not usually included in any of the four lobes discussed lies buried in the depths of the lateral sulcus. This site of cortex, called the insula, overlies the site where the telencephalon and diencephalon fused during embryological development. The portion of a given lobe overlying the insula is called an operculum.

The cingulate gyrus, superior to the corpus callosum, can be followed posteriorly to the splenum of the corpus callosum, where it then turns inferiorly as the narrow isthmus of the cingulate gyrus and continues as the parahippocampal gyrus of the temporal lobe. These two gyri give the appearance of encircling the diencephalon and they, together with the olfactory bulb, olfactory tract, and other small cortical areas, are often referred to separately as the limbic lobe. The limbic lobe and structures with which it is interconnected make up the limbic system. This is important in emotional responses and drive-related behaviors.

Frontal Lobe: Four gyri make up the lateral surface of the frontal lobe. The precentral gyrus is in front of and parallel to the central sulcus; it extends to the precentral sulcus. The superior, middle and inferior frontal gyri are oriented parallel to each other and approximately perpendicular to the precentral gyrus. The superior frontal gyrus continues onto the medial surface of the hemisphere to the point of the cingulate sulcus. The inferior frontal gyrus is divided into three parts: 1. The orbital part, which is most anterior and continuous with the inferior (orbital) surface of the frontal lobe; 2. The opercular part, which is most posterior and forms a portion of the frontal operculum; and 3. The wedge-shaped triangular part, which lies between the other two. The olfactory sulcus contains the olfactory bulb and tract.

The frontal lobe contains four functional areas:

1. The primary motor cortex is composed of the precentral gyrus. It contains many of the cells of origin of descending motor pathways and is involved in the initiation of voluntary movements.
2. The premotor area is made up of the remainder of the precentral gyrus together with adjacent portions of the superior and middle frontal gyri; it is functionally related to the initiation of voluntary movements.
3. Broca’s area, the opercular and triangular parts of the inferior frontal gyrus of one hemisphere (generally the left), is important in the production of speech and written language.
4. The prefrontal cortex comprises the remainder if the frontal lobe. It is involved in what may be described as personality, insight, and foresight.

Parietal lobe: The lateral surface of the parietal lobe is divided into three areas: the post-central gyrus, the superior parietal lobules, and the inferior parietal lobules. The postcentral gyrus runs posterior to the central sulcus and parallel to it while extending to the postcentral sulcus. The intraparietal sulcus runs posteriorly from the postcentral sulcus toward the occipital lobe, separating the inferior and superior parietal lobules. The inferior parietal lobule is composed of the supramarginal gyrus and the angular gyrus. The extensions of the precentral and postcentral gyri onto the medial surface of the hemisphere are sometimes referred to as the paracentral lobule, which is partly in the frontal lobe and partly in the parietal lobe.

The parietal lobe is associated with three functions:

1. The postcentral gyrus generally coincides with the primary sensory cortex; that is, it is concerned with the initial cortical processing of tactile and proprioceptive (sense of position) information.
2. Much of the interior parietal lobule of one hemisphere (generally the left), together with portions of the temporal lobe, is involved in the comprehension of language (Wernicke's Area).
3. The remainder of the parietal cortex subserves complex aspects of orientation of the individual in space and time.

Temporal lobe: The lateral surface of the temporal lobe is composed of the superior, middle, and inferior temporal gyri. The inferior temporal gyrus continues onto the inferior surface of the lobe. The remainder of the inferior surface is made up of the occipito-temporal (fusiform) gyrus and the parahippocampal gyrus, separated from each other by the collateral sulcus. The parahippocampal gyrus is continuous with the cingulate gyrus around the splenum of the corpus callosum by way of the isthmus of the cingulate gyrus. The anterior end of the parahippocampal turns backward and forms a medially directed bump called the uncus. Folded into the temporal lobe at the hippocampal sulcus is an area of cortex called the hippocampus, which is part of the limbic system.

The temporal lobe is associated in general with three functions:

1. A small area of the superior temporal gyrus is the primary auditory cortex.
2. The parahippocampal gyrus and hippocampus, as part of the limbic system, are involved in emotional and visceral responses.
3. The temporal lobe is involved in complex aspects of learning and memory recall.

The second and third functions may overlap to some extent. Portions of the limbic system, particularly the hippocampus, seem to be important for memory processes.

Occipital lobe: The lateral surface of the occipital lobe is of variable configuration. Its gyri are simply referred to as lateral occipital gyri. On the medial surface, the wedge-

shaped area between the parieto-occipital and calcarine sulci is called the cuneus. The gyrus inferior to the calcarine sulcus is the lingual gyrus. The transition from lingual to parahippocampal gyrus occurs at the isthmus of the cingulate gyrus.

The occipital lobe is more or less exclusively concerned with visual functions. Primary visual cortex is contained in the walls of the calcarine sulcus and some of the nearby cortex. The remainder of the lobe is referred to as a visual association cortex that is involved in higher order processing of visual information.

Diencephalon

The diencephalon has four main substructures: thalamus, hypothalamus, epithalamus, and subthalamus. The thalamus is an ovoid nuclear mass, part of which borders on the third ventricle. Posteriorly the thalamus protrudes over the most rostral portion of the brainstem. The thalamus is a nuclear mass of great importance in both sensory and motor systems. No sensory information, with the exception of olfactory information, reaches the cerebral cortex without prior processing in thalamic nuclei. The complex anatomical loops characteristic of motor systems involve pathways between the cerebellum and cerebral cortex and between basal ganglia and cerebral cortex; these typically involved thalamic nuclei as well.

The hypothalamus is inferior to the thalamus. Its inferior surface is one of the very few parts of the diencephalon visible on an intact brain. This inferior surface includes the infundibular stalk and two mammillary bodies. The hypothalamus is the major visceral control center of the brain and is involved in limbic system function as well.

The epithalamus comprises the midline pineal gland and several small neural structures.

Brainstem

The brainstem is divided into the midbrain, the pons, and the medulla. The tectum (roof) of the midbrain, that part dorsal to the cerebral aqueduct, consists of paired bumps called the superior and inferior colliculi. The paired cerebral peduncles constitute the remainder of the midbrain. The pons consists of a protruding basal portion and the pontine tegmentum that forms part of the floor of the fourth ventricle. The medulla consists of a rostral open portion, containing part of the fourth ventricle, and a caudal closed portion, continuous with the spinal cord.

The points of attachment of most cranial nerves are generally seen beginning at this level. The olfactory tract is located in the olfactory sulcus, lateral to the gyrus rectus, and is attached directly to the cerebral hemisphere. Cranial nerve I (olfactory) is a collection of bundles of very fine axons called olfactory fila that terminate in the olfactory bulb at the anterior end of the tract. Cranial nerve II (optic nerve) joins to form the optic chiasm, in which half the fibers of each nerve cross to the opposite side. The optic tract proceeds from the optic chiasm to a thalamic nucleus. Embryologically, optic nerves are

outgrowths of the diencephalon and are tracts of the CNS, but they are treated as cranial nerves because of their course outside the rest of the brain. Cranial nerve II is the only one that projects directly to the diencephalon.

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 heterogeneity 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.