

2 | Meet Your Brain

Not Chaos, not
The darkest pit of lowest Erebus,
Nor ought of blinder vacancy, scooped out
By help of dreams - can breed such fear and awe
As fall upon us when we look
Into our Minds, into the Mind of Man -
My haunt, and the main region of my song.

--William Wordsworth, The Recluse, Prospectus.

I am trying, in this book, to suggest what neuroscience can say to people like me who like to think about literature, and how literature works in human beings. In the jargon, we "theorize." That is, we wonder about things like, How is literature made? How do writers come into being? How do readers read and enjoy--what is the psychology of that? Why do we feel real emotions toward imaginary people? I am asking in this book, How does our growing knowledge of the brain help to answer such questions?

Admittedly, literary processes may be too complicated for today's neuropsychologists. They address simple behaviors, like perceiving the left side of the visual field or knowing how to move a screwdriver. Nevertheless--and that is my purpose in this book--they can tell us things that bear on how we think about literature and what we say about it. We theorizers would do well to be consistent with this growing body of knowledge.

Clearly, for thinking about literature, we do not need to know all the things neurologists know. We do not have to concern ourselves with diseases of the brain. We need not memorize the system

of veins and arteries or the outer membranes. The senses of taste and smell matter little to literature, except as we imagine tastes and smells. We will need to understand only the basics about neurotransmitters. We do not have to be concerned about muscular motion, except in a general way. I can confine this introduction to the brain to things that I think relevant to those literary matters.

We will be interested primarily in brain function or the branch of neuroscience called "neuropsychology." It connects behaviors like writing and reading to systems within the brain--never to a single locus! That would be the nineteenth-century fallacy of localization, that led ultimately to the bump-psychology of the phrenologists. We are always dealing with a distributed system, often widely spread around the brain. That is why, when neurologists talk about this or that part of the brain, they say over and over that such-and-such a region "is involved in," "is essential to," "aids in," "plays a key role in," "helps process information about," and other phrases to keep us mindful of the brain's complexity. Locations in the brain are parts of systems.

In this first chapter, I am providing an introduction to the physical brain for readers who are new to neurology, neuroscience, and neuropsychology. If you are well acquainted with the pars triangularis, if you have delved into the mysteries of the nucleus reticularis thalami, you had best skip right over to the section of this chapter on emotional pathways.¹

The brain

A normal human brain weighs about three and a half pounds (1.6 kilograms). In size and shape it looks about like a big man's two fists pressed together along the second bone of the fingers. (See Figure 2-1a, b, and c and Animation A2-1) As we grew during our embryonic and foetal stages, our brains became compressed within the skull and folded to make bulges and grooves. If one were to spread the cortical surface out flat, it would be about the size of a card table. A bulge produced by

¹ I list here some of the textbooks and other basic books about the brain that have helped me write this introduction: Bear, Connors, and Paradiso 1996; Bownds 1999; Damasio 1999; Gazzaniga, ed. 1993, 1999; Heilman 2002; Heilman and Valenstein 1993; Kalat 2001; Kaplan-Solms and Solms 2000; Mesulam 2000; Pally 2000; Panksepp 1998; Passingham 1993; Solms and Turnbull 2002. I am exceedingly grateful to Dr. Alonso Riestra who has gone over the chapter in detail and rescued me from many an error. ..

this squeeze of a flat surface is called a gyrus, and the groove, if deep, a fissure, if less deep, a sulcus (plurals: gyri, sulci).

Neurologists speak of our brains as divided into two hemispheres (left and right) and four lobes, (as in Figure 2-2). These lobes form the cerebrum, the outer layers of the brain. The "longitudinal fissure" divides the brain port and starboard, and the central sulcus divides the cerebrum fore and aft. The occipital lobe is at the back of the brain, and the frontal lobe, logically enough, at the front, that is, in front of the central sulcus. The parietal lobes lie behind the central sulcus and form the roof and side walls of the brain. The temporal lobe is at the bottom of the cerebrum, inside our temple, divided from the frontal and parietal lobes by the Sylvian or lateral fissure. Figure 2-2 also shows some of the brain's other structures, the cerebellum beneath the occipital lobe, the brain stem running downward from the center of the brain, and the tip of the spinal cord that runs from our lower bodies up into the brain. (See also Animation A2-2 for a view from underneath the brain.) We will come back to the lobes in later chapters when we consider how they interact to make up our perceptions, actions, feelings, and thoughts.

Like other parts of our bodies, a brain is composed of cells. For our purposes, we can focus on one kind of cell, the neuron. (See Figure 2-3.) A brain contains about 100 billion neurons, nerve cells, which are specialized to produce the mind's activities and the body's movements. Neurons are tiny and in a space the size of a pinhead there can be six million interconnected neurons. The outer surface of the brain contains 300 million feet of wiring packed with other cells besides neurons into a one-and-a-half quart volume in the total brain. That is another reason one cannot "locate" brain functions in specific areas. In any space big enough for us to specify, there are simply too many neurons involved to be sure they have only one function. Think how small the brain of an inch-long lizard must be, yet it functions in all kinds of complicated ways. So with insects, which have no brains at all, only ganglions, clusters of nerve cells, scattered around their tiny bodies.

Figure 2-3 shows a schematic one kind of neuron. (There are several different shapes of neurons but they all function the same way.) A neuron consists of the cell body or soma where small

elements within the cell body like the mitochondria supply energy for the cell's activities and keep the chemicals in the cell balanced. The nucleus of the cell contains the genetic material (DNA) that determines what proteins will be synthesized in the rest of the cell body. Outward from the soma, in one direction, a dendrite extends like a series of twigs branching out from the cell body. In another direction an axon, a long fiber, extends from the soma. The axon reaches out to form a synapse with the tip of a dendrite of another cell, and it is across this tiny synapse that information passes. (See Figure 2-3.)

Neurons transmit information, that is, their "on" or "off" state, to one another across tiny synapses. These are 20 nanometer (2/100,000 millimeter) gaps, at which information can be modulated or inhibited or simply passed on. (See Figure 2-3.) Any given neuron may have 1,000 to 10,000 synaptic connections, and they may run to a dendrite, a cell body, another axon, or even the same axon. Thus information can be transmitted, changed (modulated), or suppressed at 10-100 trillion, 10-100,000,000,000,000, synapses (give or take many billion). Some say the human brain is the single most complicated object in the universe. Even allowing for human conceit, I can believe it.

Information--whether the neuron is resting or active--passes from neuron to neuron in the form of chemicals called neurotransmitters. These are what neurochemists and neuropharmacologists study, and they are exceedingly complex. Estimates are that there are as many as 200 different neurotransmitters, only 50 or so of which neurochemists have investigated closely. To make matters still more complicated, a given neurotransmitter may do different things. Some stimulate, some inhibit, and a single neurotransmitter may behave differently at different points in the brain.

Fig 2-3 shows how the cells communicate. A very few neurons that have to work especially quickly communicate by pure electrical connections, but the great majority use chemical neurotransmitters as shown. When a dendrite on the receiving (or post-synaptic) cell receives a chemical signal from an axon, it opens channels through which ions travel. These reduce the normally negative charge inside the cell, creating a little blip of less negative, i.e., relatively positive, voltage. The voltage blips from the many synaptic connections onto a given neuron's dendrites add

and subtract to come to a net electrical stimulus that enters the cell body. If this is large enough, it triggers the cell body to generate an action potential, a millisecond change of voltage toward positive. The action potential then flows out along the long tube of the axon. When it reaches the little bulge at the tip of the axon (the bouton), the electrical pulse causes the cell to create tiny, microscopic balloons or bubbles (vesicles) containing some particular neurotransmitter that that cell generates. These vesicles fuse with the cell membrane, dumping their neurotransmitter into the tiny synaptic gap. The neurotransmitter then stimulates the next neuron in the pathway by the same process. Each little vesicle dumps its neurotransmitter into receptors on the post-synaptic neuron. These then become the electrochemical signals that trigger dendrites on the next cell. The transmission proceeds from cell to cell this way, branching, adding, inhibiting, in unbelievably complicated ways, ways so complicated that neurologists can trace only the largest paths of transmission.

The excess neurotransmitter, not taken up by the post-synaptic cells's receptors, is returned to the pre-synaptic neuron or disposed of in the salty liquid between the cells. That saline solution presents a problem, because a salt solution conducts electricity. The action potential, the voltage pulse, traveling along the long tube of the axon could leak out into the conductive solution surrounding the axon. To prevent that, neurons whose axons are long, that is, neurons that are not closely packed, that have to travel a distance, need some sort of insulation. They become myelinated. That is, in fetal development and all through childhood and adolescence, neurons are growing a fatty sheath, myelin, that serves, roughly, like the insulation on an electrical wire. (More precisely, it allows for amplifying the action potential at intervals as it decays along the length of the axon.) This fatty myelinization is what gives whiteness to the "white matter" toward the center of the brain (where the neurons cover some distance). The "gray matter" on the outer surface of the brain contains mostly cell bodies.

Our neurons myelinate over years. In a newborn infant's brain, little myelinization has taken place, and consequently its motions and other actions governed by long axons are, as we say, "infantile," that is, erratic and uncontrolled. Only during early childhood does the human brain begin

to function like a human brain as more and more synapses are developed and more and more myelination takes place. And myelination is not completed in our brains until early adulthood.

How do we find out about the brain?

Clinico-anatomical method is the proven, traditional procedure. A patient suffers damage to the brain, from a stroke, an accident, or a tumor--whatever. The neurologist compares the resulting changes in behavior to the anatomical changes in the brain and tries to derive the system--the multiple parts and pathways of the brain--involved in that behavior.

The gold standard in this method is "double-dissociation." Suppose, in one individual, something has damaged area X and the individual shows a deficit in behavior A but no deficit in behavior B. Then suppose that, in another individual, something has damaged area Y and that person shows no deficit in behavior A but fails at doing B. At that point the neurologist can say with some confidence that area X is "involved in" doing A, and area Y is "involved in" doing B. In effect, each lesion has served as an experimental control on the other. "Involved in" proves a useful term because, always!, when we talk about behaviors, we are dealing with systems rather than a single part of the brain doing this or that.

Early neuropsychology tended to look at behaviors broadly and relate them directly to brain regions. Thus, Carl Wernicke in the 1870s distinguished fluent from non-fluent speech. Non-fluent aphasia results from frontal damage to the left hemisphere, but fluency (to be sure, a nonsensical fluency) is retained if the damage occurs further back in the same hemisphere.

"Fluency" is a pretty large term. Today's "cognitive" neuropsychologists would tease out the components of such a function. Thus fluent speech might require a lexicon of semantic meanings, a library of mouth movements, and a dictionary of heard letter-sounds for recognizing that one is speaking correctly. Today's neuropsychologists would hypothesize some such set of connected but independent "modules." They would then, on the basis of psychological experiments, connect these modules in the kind of complicated block diagram that computer scientists use. They would be using the diagram to show how they think these modules are interconnected and how they depend on one

another in various sequences and directions (feedbacks and feedforwards). Today's neuropsychologists would then go on to relate these different units to different brain regions as determined by clinical data or brain scans. The whole discipline has become far more precise than, say, Carl Wernicke's early efforts at diagramming language functions.

The nineteenth-century neurologists had to wait until the patient had died to look at the damaged brain. Today, electronics and computers have given neurologists powerful techniques for scanning the brain. Electroencephalograms (EEG), positron emission tomography (PET), computed tomography (CT), functional magnetic resonance Imaging (fMRI) and other techniques can literally give us a picture of the brain in action. These techniques have different strengths and weaknesses. Some are better than others at picking out details of a millimeter or so. Some can operate faster than others. Some respond to blood flow (and hence react slowly), others to electrical voltages (and react quickly). Powerful as these techniques are, no single method serves all purposes and so answers the neurologists' prayers. None can isolate particular functional systems--yet.

How do we find out about the brain? I have already mentioned the clinico-anatomical method, and double dissociation, which are standard for neuropsychologists. But once the neuropsychologist has located a lesion or made a certain area of the brain light up in a scanner, how are these areas related to the rest of the brain? If you were to dissect a brain, you would find marked differences in texture. The outer surface is unmyelinated "gray matter," and the inner bulk is myelinated "white matter." Within the brain, there are a variety of different textures. Some neurons occur in a clearly distinguishable mass or nucleus (plural, nuclei). Others occur in a thin sheet or cortex (plural, cortices). And so on through a variety of the mouth-filling Greek and Latin names that have come down to us from medieval medicine. (They are supposed to ensure precision, but, unfortunately, neurologists often use several different terms for the same thing.)

In the early twentieth century, the German neuroanatomist Korbinian Brodmann created a "cytoarchitectural map" of the brain (cyto- means cellular). That is, he mapped the different areas of the brain based on differences in the microscopic texture. His map and numbers remain standard to

this day, although the numbers do not mean anything--they simply record the order in which he studied the different areas. It is a formidable picture to the layperson with its crowded little triangles and squares, but a useful one. Neurologists (and I) will refer to Brodmann Area 17 (or simply "BA 17" or "area 17") and know that they are referring to the primary visual cortex V1 at the back of the brain. Figure 2-4a gives a simplified version of Brodmann's map, and Figs. 2-4b and c apply the map to photographs of the brain. Figure 2-4d applies Brodmann's numbers to various functional areas that we will have occasion to refer to in later chapters. Both will prove useful when we get to more literary matters. In the meantime, we need to consolidate more knowledge about the brain.

By and large . . .

We can begin with some "by and large" generalizations about our brains.

"By and large," we can say that a brain has one purpose and one purpose only: to move a body. (It tries to maximize the organism that owns the body's chances of evolutionary success through survival and reproduction.) Trees and sponges and polyps do very well without brains, because they do not have to move.

"By and large," we can say that, in the human brain, the back part, behind the central sulcus, has to do with sensory perception. The front part, in front of the central sulcus, the frontal lobe, has to do with executing and planning for motor activity. By and large, we can say that the more frontal the area in the frontal lobe, the more removed the thinking from immediate action. That is, we use our prefrontal lobes when we inhibit motor actions and plan far into the future. It is these far forward, last-developing parts of the brain that allow us to think abstractly about politics, ethics, cosmology, and even literary criticism.

The crude "front" and "back" in that paragraph signal me that it would be useful at this point to introduce some of the terms neurologists use for speaking about different areas in the brain. I have already mentioned gyrus, sulcus, and fissure, central sulcus, and the four lobes. Here are navigational terms:

anterior	forward	posterior	backward
inferior	lower	superior	higher

lateral	out to the sides	medial	toward the midline
caudal	toward the spinal column	rostral	toward the nose

"Dorsal" and "ventral" are a little tricky. In the spinal cord, the terms follow their Latin roots: "dorsal" means toward the back, "ventral" toward the belly. In an animal like a dog, all through the body, "dorsal," toward the back, means up and "ventral," toward the belly, means down. But, in the human brain, so as to be consistent with the dog and other mammals, "dorsal" means toward the crown of the head, and "ventral," toward the chin, like superior and inferior. The meanings of the terms have rotated 90° from their meanings in the spine.

Two other terms parallel, roughly, anterior and posterior. "Caudal" means, in animals, toward the tail, in us toward the spinal column. "Rostral" means toward the nose or beak. These terms are useful for linear parts of the nervous system, like the spinal cord or the brain stem that are not necessarily straight up and down or horizontal.

"By and large," we can parcel out our three major sensory modalities, sight, hearing, and "touch," among the three pairs of lobes behind the central sulcus. The occipital lobe has to do with vision. Hearing takes place in the temporal lobe. "Touch," although one thing in ordinary speech, includes a variety of different sensations with different peripheral, spinal, and brain processors: vibration, temperature, light touch, and pain. We deal with limb position or "sensorimotor" information in our parietal lobes.

Like the lobes, the hemispheres specialize. "By and large," most humans (95% or more) deal with language primarily in the left hemisphere, and we process non-verbal (including "visuospatial") information in the right hemisphere. In infancy, our right hemispheres "come online" first and the left later. That is why we humans come to language only after a year or more after birth.

"By and large," the left hemisphere deals with sequential information and the right with holistic. "By and large," the left hemisphere deals with logic and the right with emotion. But even this is specialized. "By and large," the left hemisphere generates positive emotions, and the right with negative.

These statements, please remember, are very "by and large." Take them as rough guidelines, not as careful, absolute distinctions. Perhaps the most important of these "by and large" statements is one that Mark Solms emphasizes. The brain is the organ in all mammals that combines information about the world outside our bodies with information from the world inside our bodies. The brain combines what we perceive "out there," like colors, shapes, sounds, or smells with feelings "in here," physiological ones like thirst or hunger and emotional ones like desire, anger, or fear.

"By and large," then, we can divide the brain's knowledge of the body that contains it into two kinds. First there is knowledge about the body's inner state, representations of the body's functions, such as maintaining temperature or blood pressure and, importantly for literature, feelings like rage or desire. The second is knowledge about what is coming into the body from outside: perceptions and sensations. By and large, that second, outer knowledge comes from the three posterior lobes involved with perception. The inner knowledge comes from the body's neural and hormonal pathways up from the spinal cord or the nerves in the head into "subcortical" structures, notably the amygdala and hypothalamus and the limbic system (associated with our emotions. We will look more closely at these pathways later in this chapter.)

Lizards and us

A useful way to start thinking in more detail about the brain draws on an idea advanced by Paul MacLean in the 1970s, the triune brain. While questioned now by many brain scientists, it will serve as an approximation. MacLean suggested that, if we consider our brains evolutionarily, we really have three brains. They are all interconnected, to be sure, but they are three rather different brains. We have a reptilian brain, a paleo- or old mammalian brain, and a neo-mammalian or primate brain. (See Figure 2-5.) In effect, they are nested, with the reptilian brain lowest and innermost, the mammalian brain surrounding and covering its top, and the primate brain on the surface surrounding the mammalian brain.

As for a reptilian brain, think of a snake, an alligator, or those little lizards that scurry away when I step out my front door into Florida's morning sun. Since the little lizards are scarcely an inch long

and their heads about a quarter of an inch, their brains are very, very small. Yet those tiny-brained creatures get along in the world pretty well. They manage their blood pressure. They find an environment that will keep their temperatures between acceptable limits. They escape the threat of me and my clomping shoes--they are so quick, that I have yet to step on one of them. And they flirt with me, puffing out the red flap under their throats when they come to watch me writing on the porch. (Or perhaps they mean to threaten me. Or suggest a phrasing.) At any rate, they do pretty well in the four basic tasks of an organism, the four F's of the medical student's old joke, feeding, fighting, fleeing, and sexual reproduction. Jaak Panksepp sums it up: "The innermost reptilian core of the brain elaborates basic instinctual action plans for primitive emotive processes such as exploration, feeding, aggressive dominance displays, and sexuality."²

In MacLean's picture, the part of our brains that corresponds to theirs is the upper brain stem, the basal ganglia surrounding it, and the reticular system that spreads all through the brain stem. In us, the brain stem is about the size of a thumb, and it extends up from the spinal cord into the center of the brain. Yet this "reptilian" brain evidently contains sophisticated enough systems for doing all these things: finding food, recognizing dangers and fleeing them, fighting enemies, and mating. MacLean thinks of the reptilian brain governing stereotyped behaviors, "hidebound by precedent," and he compares it to Freud's compulsion to repeat, that is, to try the same solution to a problem over and over.

Mammals evolved, we now believe, from the dinosaurs, and, for thinking about the brain, we can ask, What do mammals do that dinosaurs and other reptiles don't? Mammals carry on all the four Fs as the reptiles do. What have they added? Fur? Warm-bloodedness, that is, an internal system for body temperature? They are probably not important for literature. Live offspring? Yes!, and further, live offspring that must be suckled. In other words, instead of laying an egg and walking away from it as a turtle or a snake does, a mammal mother has to form a relationship with her offspring. And her progeny have to form a relationship with her. As Harry Harlow showed in some

² Panksepp 1998, Fig. 3-1.

famous experiments rearing monkeys with mechanical mothers, the infant's developing appropriate behavior towards others of its species depends on that early mothering.³ Deprived of it for a long enough time, they do not, as adults, learn to relate to others or to mate normally.

In short, the newborn mammal depends on its mother in a way that baby reptiles do not. Moreover, mammals continue to have relationships as adults, like the herd of sheep with a ram as leader, a pack of dogs with the alpha dog as boss, or the complicated and bloody social arrangements of a pride of lions. These groups presuppose various emotions: fear, anger, desire, perhaps even grief or love. Individual mammals clearly show in their behavior emotions like fear and rage and sexual desire. But so do reptiles.⁴ Panksepp sums up the difference: "The old-mammalian brain, or the limbic system, adds behavioral and psychological resolution [nnh: I read that as fine-tuning] to all of the emotions and specifically mediates the social emotions such as separation distress/social bonding, playfulness, and maternal nurturance."⁵

In general, mammals, because of their period of dependency, have more to learn about how to get along with their fellows than reptiles do. Thus we see lion cubs play-fighting with each other, learning how to fight but controlling the impulse to bite. Young mammals of most species enjoy roughhouse play.⁶ And play, surely, is the beginning of something like literature.

In short, mammals add social behavior to the reptile repertoire: mothering, play, and group and kin relationships. These behaviors add considerably to the complexity of mammalian life and presumably, therefore, to the brain that governs it.

The mammalian brain where these mothering and social activities are monitored corresponds roughly to the human limbic system. This is a group of structures and clusters of cells (nuclei) perched on top of and around the upper brain stem. MacLean speaks of the "paleo-mammalian" brain because it does not change as mammals evolve in other ways. It is the major part of the system by which we humans feel emotions. (See Figure 2-6.)

³ Cole and Cole 1996, 241-42.

⁴ Recent papers by Cabanac and Cabanac suggest that emotion entered the evolutionary lineage much earlier, between amphibians and reptiles (Cabanac 1999; Cabanac and Cabanac 2000.)

⁵ Panksepp 1998, Fig. 3-1.

⁶ Panksepp 1998, ch. 15.

This paleo-mammalian brain also adds to the reptilian core a primitive cortex, and this does grow larger as mammals evolve from, say, rabbit to cat to monkey. This primitive cortex provides the basis for a thinking, planning brain.

When I first became interested in what neurology might tell us about literature, I assumed that literature was a very high-level function. After all, one has to read, which can take a human child several years to learn. One has to understand the meanings of words and actions and relationships. One has to understand and empathize with fictional characters. One has to interpret along moral or political or philosophical lines--at least you have to if you are a critic like me. Literature involves these high-level functions--partly. But I have come to realize that the bulk and core of the literary experience, the emotions we feel--these come from that mammalian brain that we share with sheep and cows and cats and dogs. Those cognitive abilities come along later.

Our pongid kin

What, then, does the primate or neo-mammalian brain, the brain of monkeys, apes and us, add? It seems to be largely a matter of degree rather than kind, with a few exceptions. One part of the limbic system evolved in such a way that the primary source of sexual stimulation became sight not smell. Further, as the primates evolved away from the other mammals, the association areas in the brain grew larger. These are the areas between the regions devoted strictly to one sensory mode like seeing, hearing, sensorimotor perceptions, or motion. Those are "unimodal" areas. The association cortices are "polymodal." They meld those separate perceptions into a coherent picture of the world and frame coherent actions upon it.

In evolutionary time, the association areas expanded to create a larger cerebrum, that is, the outer cortex of the brain. The frontal lobe in particular enlarged. The primates became able to do more planning. To some extent they could use tools, they could choose seasonal fruits and berries as opposed to grazing or hunting randomly, and they began to organize into quite complicated social groups. One could draw a computer analogy: the reptilian and mammalian brains supply the read-only memories and the operating system for our brains, the kind of thing that goes into operation

when you turn the computer on. The neomammalian or primate brain supplies the applications, the specialized programs and, in particular, the neural networks some computer programs provide that resemble our human cognitive abilities. When you do a "fuzzy search" in Google, you are using a computer program that mimics things our frontal lobes can do.

Primate brains, moreover, are not limited to basic survival operations (read-only memory and operating system). For example, in Borneo, a certain nut provides a lot of the protein for the diet of the orang-utans. A troupe of orang-utans on one side of a certain river has developed a way of opening that nut that gets more of the meat out--a considerable advantage. Remarkably, these orang-utans teach the technique to their offspring. This is cultural knowledge. The orang-utans on the other side of the river have not developed the technique. In effect, we are looking at two troupes with different cultures, and one has a distinct evolutionary advantage over the other. If there were no humans destroying their habitat, we might expect, in a relatively small number of generations, the genes of the more "sophisticated" orangs to outnumber the others in the gene pool. In other words, in the right environment, a purely cultural change can lead to an evolutionary change. This is an example of "Baldwinian evolution," a more rapid system of evolution than Darwinian, of which more later. It may help us understand how language (and literature?) came to be.

The human brain differs from the brains of the other primates mostly in degree. (Hence neuroscientists can use experiments on apes to understand the human brain.) Our frontal lobes and other association areas have become much larger, however. Although an orang-utan weighs about the same as a man, the man's frontal lobe is about five times larger.

It seems likely therefore that the earliest hominids were cleverer than the other primates and were able to spread all over the globe as we humans have. In modern humans, the prefrontal cortex, the prow of the brain, so to speak, the anterior part behind our foreheads, became very large relative to the other primates. (The "prefrontal" cortex should really be called just the frontal cortex, but an early misnomer stuck.)

This prefrontal cortex is the most advanced part of our brains, where our most complex planning and thinking takes place, the thinking farthest removed from action. In us, this large prefrontal cortex does not fully take shape until our mid-twenties. If the development of the individual mirrors the development of the species (Haeckel's Law), then the prefrontal cortex was the last part of our brains to evolve. Teenagers, thus, lack other humans' best planning and thinking--but no parent waiting up at 2 a.m. needs a neurologist to know that. Adolescents have overactive hormones and underactive inhibiting systems, and that is why teenagers are the way they are.

Further, sometime in the past--the best guess is 80-120,000 years ago--we developed the modern human species, homo sapiens sapiens--us--as opposed to homo sapiens neanderthalis and other hominid types. Sometime in the past--the best guess is 60-100,000 years ago--we developed language. (I will follow the neurologists' convention and speak of language as in the left hemisphere. It is for right-handers, but for about 50% of left-handers, it is in the left hemisphere, for 25% in the right, and for 25% distributed between both. Thus, the language centers occur in the left hemisphere for about 95% of humans.)

Chimpanzees have the slight swelling in the left hemisphere of the brain that marks, in humans, the language centers and systems. But chimpanzees and other primates lack language and the results from efforts to teach them demonstrate nothing like the grammars all human children acquire with ease. By grammar, I mean simply our use of complicated nestings and interrelations among words to form sentences. The key term is "recursion."⁷ One sentence can call another sentence, embedding it within itself, as when I write, "I remind you that I was talking about adolescents." Something happened to give us a language based on a universal grammar shared by all humans, which included recursion, and no one knows what.

Again, sometime in the remote past, we developed art. By 40,000 years ago, humans were burying their dead with ceremony and making beads, pendants, and figurines of female bodies. Recently, even earlier evidence turned up: an incised piece of red ocher, about 77,000 years old,

⁷ Hauser, Chomsky, and Fitch 2002.

discovered in South Africa.⁸ This piece of criss-crossed ocher tells us that by that time we had learned decoration. We had gained the ability to use our advanced brains for non-utilitarian purposes. Presumably, we learned to use speech the same way, and literature was born. Because literature consists of language, one particular part of the cerebrum plays a key role.

The Temporal Lobes

"By and large," the temporal lobes (see Figure 2-7) deal with auditory perception. Also, in more than 95% of humans the left temporal lobe is specialized for understanding and generating language. We can think of this lobe as divided into four gyri, called, logically enough, superior, middle, inferior, and, underneath the brain and inside it, the fourth gyrus. We can take them from the top down.

The anterior portion of the superior temporal lobe has to do with processing information from our auditory nerves--our ears, It is here that we establish the directions and distances of sounds, for example. As we move posteriorly along the lobe, we come to the famous Wernicke's area, discovered in the 1870s to be crucial for understanding and generating language. (See Animation A2-3.) Just anterior to Wernicke's area is Heschl's gyrus which does some preliminary processing of information from the ears and auditory nerve.

When we speak to one another, the sounds we make vary tremendously. When I say my daughter's name, "Kelley" it sounds very different from the way my wife says "Kelley." Pitch, speed, intonation all differ, yet nobody has any trouble recognizing the name no matter who speaks it. If you say two related words, like "bat" and "but" into an oscilloscope you can see a picture of what the waveforms look like. The b in "bat" and the b in "but" look different. The t's likewise. Yet we recognize these basic sounds, these phonemes, for what they are. Together Heschl's gyrus and Wernicke's area in the left hemisphere perform the remarkable trick of pulling out from a continuous stream of sound a /p/ or a /b/ or a /u/, that is, the separate phonemes (that constitute the smallest units of speech). Some system in our left temporal lobes has done a quite amazing job of decoding.

⁸ Wilford 2002.

This has to happen quite early in the processing of language but just how and precisely we do not know.

The term "inferior temporal region" brings together the posterior portions of the middle, inferior, and fourth gyri (BA 37 in Figure 2-7). This area is involved in recognizing the objects we perceive in the world. In general, this inferior temporal area seems to contribute to our ability to place things in categories, to see a robin and say "bird." Some stroke victims can say only "bird" and not, "robin."⁹

We have been looking at the posterior region of the inferior temporal lobe. The anterior region includes the frontal areas of the middle, inferior, and fourth gyri plus the "temporal pole," that is, the downward tip of the lobe. Lesions here lead to problems in naming things, possibly because of memory loss, possibly because of vocabulary loss. Area 38 at the temporal pole seems to be particularly important.

Damage to the brain can sometimes have strikingly limited effects: patients can name things you can manipulate (tools, for example), but not edibles or animals. Or they can give proper names but not common nouns. Apparently, and, to me, quite remarkably, certain categories are mapped into our brain anatomy (innately? through learning?).

Being verbal, all these activities take place (in most people) in the left hemisphere. In the right hemisphere, the anterolateral temporal (that is, anterior + lateral) region has to do with recognizing the emotional quality of a facial expression, someone who looks angry or afraid or sad.

The medial temporal lobe, within the hemispheres' areas 27 and 28 (Figure 2-7c), includes structures associated with the hippocampus and the amygdala tucked inside the temporal lobes (hence not shown in Figs. 2-7a or 2-7b but in Figure 2-7c). These are important parts of the limbic system, the old, mammalian brain. The amygdala (inside the temporal lobe) is crucial to fear and memories of fear and the "fight or flight" response. It is concerned with self-preservation. The hippocampus (also inside the temporal lobe) is crucial as a preliminary stage to forming long-term memories. It is important for expressions and feelings of sociability and (in MacLean's phrase) "other

⁹ Mesulam, ed. 2000, 338.

preliminaries of copulation and reproduction." The hippocampus is important for laying down memories and, in particular, in remembering spatial locations. (London taxi drivers, who have to take a three-year course in finding their way around that magnificently haphazard city, have enlarged regions in their hippocampi.¹⁰) Damage to the left hippocampal system affects verbal material but not nonverbal and, conversely, damage to the right affects visual and auditory patterns, but not verbal material.

Transmitting information

We began with the neuron, and we have looked at various structures and their functions within the total economy of the brain. How those functions are achieved comes from the transmission of chemicals within the brain. The chemicals plus the neurons transmit information. As we noted at the beginning of this chapter, neurons receive neurotransmitters, some exciting the cell, some inhibiting it, and if these plus and minus signals add up to a threshold amount, they trigger the cell to send an electrochemical impulse down its axon and to bubble out neurotransmitters to the next cell.

We can distinguish two kinds of transmission. One takes specific pieces of information from one neuron to the next and then to the next and so on. This kind of transmission focuses very tightly. A particular cell in the retina will send information to a particular neuron in the visual cortex all the way at the back of the brain. These pathways are quite narrow, and the rest of the brain remains untouched by this transmission. The other kind of transmission involves widespread effects through large areas of the brain. We can distinguish these two kinds of transmission by various terms. Some speak of "content of consciousness" and "level of consciousness." I like M.-M. Mesulam's terms: "channel" transmission as opposed to "state" transmission. Perhaps we could even borrow a couple of literary terms and speak of "content" and "style."

Channel transmission uses three main neurotransmitters. Glutamate and aspartate are the two chief exciters of neuron activity. GABA (gamma-aminobutyric acid) is the main inhibitor, involved in muscle relaxation, sedation, sleep, and diminished emotional reaction.

¹⁰ Maguire et al. 2000.

State transmission works very differently. State transmission does not proceed along the narrow channel of neuron-to-neuron transmission, for there are no specific pathways. Rather, there are cells clumped together in nuclei in the brainstem with their axons going to many different areas in the higher centers of the brain. These neurotransmitter-generating cells in the brainstem cause widespread, global change. The affected neurons may at the same time be influenced by other neurotransmitters from the brain stem. Neurotransmission is a very complicated business.

These chemicals from the brain stem are called neuromodulators, because they exert global effects, modulating the activities of other systems, by such things as mood, attention, arousal, or sleep-and-waking. Because their names come up in discussions of psychological (hence, literary) functions, we do well to become familiar with four of them:

acetylcholine, acting through "cholinergic" neurons, affecting arousal, attention, learning, mood, and sleep, waking, and dream. It is used in muscle action all through the body.

serotonin, influencing appetite, sexual activity, aggression, body temperature, sleep, mood and distractibility

norepinephrine (abbreviated NE) or, in the U.K., noradrenaline (NA) involved in pain reduction, attention and motivation. Regulates blood pressure and prompts extreme arousal and the "fight or flight" response

dopamine (abbreviated DA), concerned in various appetites, an important part of the brain's "reward" system, causing feelings of wellbeing

Further, the body, at sites far from the brain, produces yet other chemicals that act on the brain as a whole. Unlike the neurotransmitters and neuromodulators which connect directly, influencing brain systems from within the brain, these chemicals affect the brain by entering the bloodstream and so acting on the brain as a whole. This group includes the hormones, such as estrogen and testosterone, generated by the sexual organs, and the steroids which play a part in stress reactions. Another group, the peptides, are produced both in the brain and in the body and diffusely affect the brain, particularly emotional systems.

Some Pathways

The brain's electrochemical way of transmitting information and having its own parts and various parts of the body influence brain processes has become extraordinarily intricate. Thanks to intense study by neuropharmacologists and animal researchers--and here I am going to draw on the work of Jaak Panksepp¹¹--we can trace some pathways useful for thinking about emotions and hence, about literature. Basically, these emotional pathways all connect one way or another with the brain stem. (See Figure 2-8.¹²)

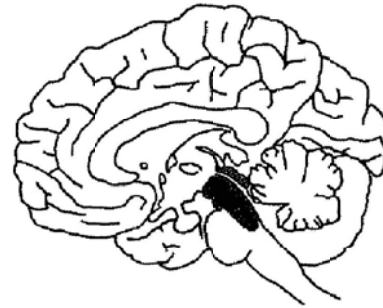


Fig. 2-8. The core emotion-generating structures

One such system is what Panksepp calls the SEEKING system, shown very simply in Figure 2-9.¹³ (Panksepp uses capitals to indicate that he is using the term in a technical sense, although, clearly, he also wants the connotations of the layperson's usage.) SEEKING includes our basic impulses to search, investigate, and make sense of the environment: an earlier term was "foraging/expectancy."

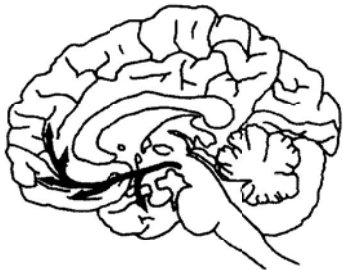


Fig. 2-9. The SEEKING system

Dopamine circuits make us feel that something good will happen to us if we interact with the environment, leading us actively to explore and seek out satisfactions. (For the technically inclined, we are dealing with the mesocortical-mesolimbic system in which dopaminergic systems in the ventral tegmental area project to the hypothalamus, the nucleus accumbens, and the anterior cingulate gyrus, an area associated with attention, and to the amygdala and other frontal lobe areas.) Mark Solms has identified this system with Freud's concept of drive. Physiologically, we have need-detecting mechanisms in the hypothalamus (the part of the brain that "reads" the body), and somehow these needs detectors activate the SEEKING system. We can also be stimulated by outer-world perceptions like, say, the sight of an ice cream sundae. Recreational drugs can take over the SEEKING system,

¹¹ Panksepp 2000.

¹² Reprinted from Solms and Turnbull (2002), Fig. 4-4, with the kind permission of Other Press.

¹³ Reprinted from Solms and Turnbull (2002, Fig. 4-3, with the kind permission of Other Press.

creating artificial appetites and artificial satisfactions and changing the levels sought by the need detectors. When we turn to literature and the arts for pleasure or understanding, we are evidently using this SEEKING system.

The LUST system is closely related to the SEEKING system. (See Figure 2-10.¹) This system takes

over in the brain from the sites where the SEEKING system stops and feeds backward onto the brain stem, where, according to Panksepp, the SELF system is based. The LUST system replaces the appetitive behaviors of SEEKING with consummatory behaviors. For example, in rats, the male stops sniffing around and mounts the female and the female arches her back. The system leads ultimately (in humans) to orgasm.

(Again, for the technically inclined, a very rough description would be that the peptides, endorphin and oxytocin, and the sexual hormones, testosterone and estrogen, act on the medial preoptical area, in males, and the ventromedial hypothalamus in females.) Outside perceptions can trigger the system's internal chemical changes, and erotic literature and pornography take lucrative advantage of this possibility. Mark Solms notes that both these systems bribe us to acquire skills, and this, I take it, provides a brain basis for the psychoanalytic concept of sublimation, which will become important when we consider "meaning" in literature (in ch. 11).

Neuroscientists distinguish among types of aggression.

The RAGE system has to do with the "hot" aggression we feel at frustration. (The "cold" aggression of predatory behavior, the leopard prowling for its next meal, lacks the feelings of rage and relates to the SEEKING system.) RAGE (see Figure 2-11² modifies heart rate and body temperature and sends extra blood to the muscles, shutting down digestive processes (your

¹ Reprinted from Solms and Turnbull 2002, Fig. 4-4, with the kind permission of Other Press.

² Reprinted from Solms and Turnbull 2002, Fig. 4-5, with the kind permission of Other Press.

mouth goes dry). These are, obviously, useful responses for survival and for sexual rivalry. In a way, the RAGE system is the opposite of the SEEKING system. The one looks for a reward,

with neurotransmitters acting upward toward cognitive systems; the other comes into being when a reward is denied and neurotransmitters act downward on the brain stem. (For the technical-minded, the neural connections for RAGE run from the medial amygdala to the medial hypothalamus and on down to the periequeductal gray in the brain stem. The neurochemicals involved are not well understood, although serotonin, GABA, opioid, and oxytocin systems seem to inhibit rage. Possibly propaganda can arouse a RAGE response--I can remember World War II movies in which I felt furious anger toward the Nazis--but good-guys-bad-guys propaganda is the only kind of literature I can think of that does. Audiences feel RAGE (frustration anger) when a work of art is interrupted, as when the sound track fails in a movie theater or the last pages of a mystery novel are missing.

As with aggression, neuroscientists distinguish kinds of anxiety: fear-anxiety and panic-anxiety, according to the medications that reduce them. The FEAR system (see Figure 2-12¹⁶) generates feelings of extreme anxiety and terror and impulses toward flight (or, in milder situations, "freezing"). It is also responsible for neurotic anxiety, a general sense of dread without any apparent cause. FEAR involves body responses as well like those of RAGE: more blood for the muscles and less for the digestive system.

For the neurophysiology-minded, the lateral and central nuclei of the amygdaloid complex trigger the FEAR system. The medial part of the amygdala triggers the RAGE response. Evidently "fight or flight" gets decided between nuclei in that small part of the brain. The neurochemistry of FEAR is not clear: the benzodiazepine receptors in the brain suppress fear, perhaps by increasing GABA or reducing glutamate in the FEAR circuit.

In the FEAR system, perceptions going to the amygdala arouse the feelings of fear. The amygdala (Joseph LeDoux has shown¹⁷) has two kinds of output. One process is rapid-response. It goes

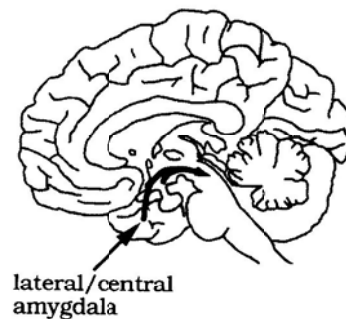


Fig. 2-12. The FEAR system

¹⁶ Reprinted from Solms and Turnbull (2002, Fig. 4-6, with the kind permission of Other Press.

¹⁷ LeDoux 1998.

directly to the hypothalamus (to reset the body) and then on to the brainstem and spinal cord to move the body. I see a snake on the closet floor and I jump back. A fraction of a second later, I realize my heart is pounding. Another fraction of a second later I realize that it is a belt that has fallen off a pair of pants. This process is more cognitive. The signal has gone more slowly from the amygdala to the frontal lobes which evaluate the stimulus and the reaction. One can easily see the evolutionary advantage in having a self-preservative system that reacts very, very fast and only evaluates the threat later. Obviously, a lot of literature uses the FEAR system: ghost and mystery stories like those of Poe or Lovecraft, adventure movies and stories, and the horror movies so popular for teen-age dates (leading perhaps to SEEKING and LUST).

The PANIC system (see Figure 2-13¹⁸) shows another kind of fear, perhaps better described as

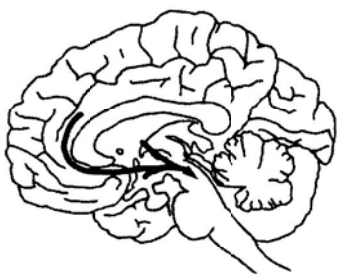


Fig. 2-13. The PANIC system

sorrow or grief, the feelings that go with loneliness or separation, the opposite of the good feelings associated with attachment and belonging. What is being studied is, like LUST, a social emotion. Psychoanalysts associate it with the infant's separation from its mother, followed by what are ponderously called in the literature, "distress vocalizations."

The baby cries. This system provides the substrate for a lot of later emotions, notably depression. At a more technical level, the PANIC system follows pain pathways from the periaqueductal gray in the midbrain and passes through areas associated with sexual and maternal behavior and, in humans, the anterior cingulate gyrus (BA 33), an area associated with attention, and on to other nuclei that have to do with sexual and maternal behavior. The neurochemistry of this system rests on the the brain's self-generated opioids, but also on some of the peptides associated with maternal behavior. Much literature plays on the PANIC system, our feelings of grief and loss: the death of a beloved character, an unhappy ending, boy-loses-girl, the "three-handkerchief movie." We often cry at movies or stories.

¹⁸ Reprinted from Solms and Turnbull (2002), Fig. 4-7, with the kind permission of Other Press.

Finally, we can conceptualize a PLAY system (although I have not learned of a brain pathway for it). All young mammals, including humans, need a certain amount of PLAY. PLAY may be necessary for juveniles to program various cortical functions. There are several kinds, exploratory, functional, building, symbolic-dramatic, and games-with-rules play, but in particular, young male mammals all seem to require rough-and-tumble play.

Panksepp concludes that the PLAY system allows the organism to exercise emotional operating systems (fear, anger, separation distress, sexuality) in the safety of one's home environment. If true emotional states intervene, the playful mood may subside, and the organism begins to address these feelings more realistically. In general, as long as PLAY seems fun, we feel joy, and we (and other primates) laugh. But we have all seen a child run home in tears, because the play got cruel--evoked a real emotion. Incidentally, laughter (like crying) comes from primitive subcortical areas of the brain that can be released by certain diseases as well as jokes (which are, of course, a form of literature). Both play and laughter serve the purpose of social bonding.

Probably, professional sports are not PLAY for the players, because it is a realistic business for them (just as a story or poem is not PLAY for the working critic). Professional sports can be PLAY only for the spectators who vicariously observe seeming PLAY in others. It is surely obvious, though, how close PLAY is to literature. Indeed, we call a drama a "play," as do the Germans (eine Spiel). (And, in French, one of the meanings of "to play," jouer, is "to act.") PLAY may also be connected to dreaming, if both are under cholinergic control.

We do not today know much about the internal circuitry of PLAY (hence no little diagram), but it seems to be linked to somatosensory information processing within the midbrain, thalamus, and cortex. Acetylcholine, glutamate, and opioids arouse PLAY, while GABA, serotonin, and norepinephrine reduce it. Any event in the environment that evokes fear, anger, or separation distress will bring PLAY to an end. I hope there will be more knowledge soon, because of the importance of a PLAY system for literature, the other arts, and child development.

A long, dark view

The "association areas" of our brains, the chunks between the areas specialized for sensory input or somatic output, have evolved and complicated themselves to an extraordinary degree. Our prefrontal cortices have grown and grown. But all this brain development, alas, has left our species in a deadly predicament. We have these wonderful prefrontal cortices that enable us to develop computers and concertos and comedies. By inhibiting the impulse-ridden limbic system, they enable us to hold off acting and plan and carry out the most abstract kinds of thinking. Thus, these same advanced parts of our brains enable us to develop bioweapons and nuclear bombs and pollution. And how do we decide what feels right, what argument will be most satisfying, what course of action will be most effective and pleasing? Not with that advanced prefrontal cortex but with the older limbic system, or, more precisely, projections from the limbic system to the frontal lobes. They generate the emotions of pleasure or displeasure as we imagine alternatives. If I can oversimplify, we are trying to govern a world that has all the enhancements and deadlinesses our prefrontal cortices can devise, with the brain of a lion or a sheep or a dog or a cat.

From an evolutionary point of view, our frontal lobes, our pride and joy as humans, are simply a highly specialized development, like the elephant's trunk, the bat's system for echolocation, or the extraordinary nose of the star mole. The elephant's trunk, the bat's echolocation, or the star mole's nose are evolutionary dead ends. They are already so complicated that it is unlikely there will be any further development of those organs. And we may well wonder if the human brain is not also an evolutionary dead end, so specialized it cannot develop further. Indeed, we may worry that, because of the discrepancy between our prefrontal capacity for abstract thought and our "cortico-limbic" sense of what feels good, we may be evolutionarily doomed by biology or, more likely, by our own greed and folly (SEEKING without frontal control).

There is hope, however. The prefrontal cortex also allows us to sense the emotions of others. We can imagine how others feel. We can be sympathetic and even empathetic and both are antidotes to greed and to foolish tendencies to ignore consequences. The question is, Will we be empathetic? Will we be--enough? Does literature provide some hope?

In sum

Even this brief survey should have made clear that doing literature, like any other human cognitive act, uses a brain and brain processes of extraordinary complexity. Yet many people who think about literature, from movie reviewers in the daily newspaper to the most sophisticated of academic literary theorists, tend to ignore the role of the brain. After all, we literary types value words. We tend to assume they have power and can impose their meanings or connotations on a relatively passive brain. But even this sketch of the brain's complexity shows that such a picture is topsy-turvy. It is the brain-mind that is active, so active it can create or exclude or change the apparent work of literature.

Our knowledge of the brain, still limited, grows and changes every day. Yet in a very broad way we can begin to sort out the complex brain processes we use in literature. At the highest level, we can think of "mind" as something we cannot see directly but observe in two different ways: objectively, looking at the body, as neurologists do; subjectively, looking at our inner experience, as psychoanalysts do. Especially for thinking about literature, we need to use both these methods.

We can divide the brain the neurologists study along general lines: motor activity to the fore, perception aft; language to the left, visual and spatial information to the right; cognition to the very front, feelings and perceptions from the body moving forward toward those cognitive centers. We have traced some of the emotional pathways in the brain that literature addresses. We create and experience literature along thpse pathways, collecting information from inside and outside ourselves and generating or interpreting language accordingly.

Thus those pathways introduce a profound paradox about literature. We do literature with our brains, and our brains, including those emotional pathways, have only one purpose, to move a body and so ensure its survival and reproduction. Yet the fundamental thing about literature is that we try simply to enjoy it (if we're not working as critics). We don't move. We don't even plan to move. When we are really "into" a work of literature, we simply do not use the parts of our prefrontal cortex for planning our thoughts and actions. Art and literature thus occupy a unique place among our perceptions. We will come back again and again to this paradox in later chapters. We have a brain

designed for the sole purpose of action, but that brain lets us enjoy the arts--precisely because we will not act on them.

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