

In 1893 Friedrich Goltz noted that removal of the cerebral hemispheres in a dog did not interfere with the cycle of waking and sleep. In the same way, anencephalic babies, who have no cerebral cortex, go to sleep and wake up like normal infants. The cortex does not control sleep rhythms. A group of nuclei situated in the brainstem between the spinal cord and the thalamus is responsible for this. Some of these neurons provoke slow-wave sleep; others, paradoxical sleep; still others are responsible for waking. Anatomically, they are part of a complex network of neurons and connections in the brainstem called the *reticular formation* (Figure 44).²⁵ Morphologically, these neurons are quite unusual. Although their cell bodies are located in the brainstem, in groups of several thousand cells, their axons spread widely throughout the brain (see Figures 11 and 44). Some send axonal branches to almost the entire cortex. Through this fanlike divergence of their axons, these very small groups of cells can exert their influence on a large part, or even all, of the brain.

As noted in Chapter 1, a team of Swedish scientists has shown that each of these small groups of neurons uses a particular neurotransmitter.²⁶ The *locus coeruleus* is responsible for waking the cortex with noradrenaline and shares this activity with a group of cells releasing acetylcholine. Another nucleus, containing serotonin, puts the cortex to sleep. Yet another induces paradoxical sleep. However, as we have already seen in connection with drinking (Chapter 4), it is always difficult to associate a particular neurotransmitter with a function. Noradrenaline is not *the* transmitter for waking, nor is serotonin *the* transmitter for sleep. Each marks a pathway containing several relays, one of which has recently been discovered to use neuropeptides.

In 1913 Henri Piéron knew nothing of neurotransmitters and peptides, but he performed an experiment that is still of great significance today. His hypothesis was that a chemical substance, a "hypnotoxin," accumulated during the day. By evening it had reached a high-enough concentration to cause sleep; it was then destroyed during the night. To test this idea, Piéron kept dogs awake for several days by tying them up during the day and taking them for walks at night. He took samples of cerebrospinal fluid when they were exhausted from their lack of sleep and injected it in the cerebral ventricles of other, wide-awake dogs, which immediately went to sleep for several hours—even during the day. This experiment has since been repeated with rabbits and cats.²⁷ Hypnotoxins *do* exist. Several neuropeptides, different from the endor-

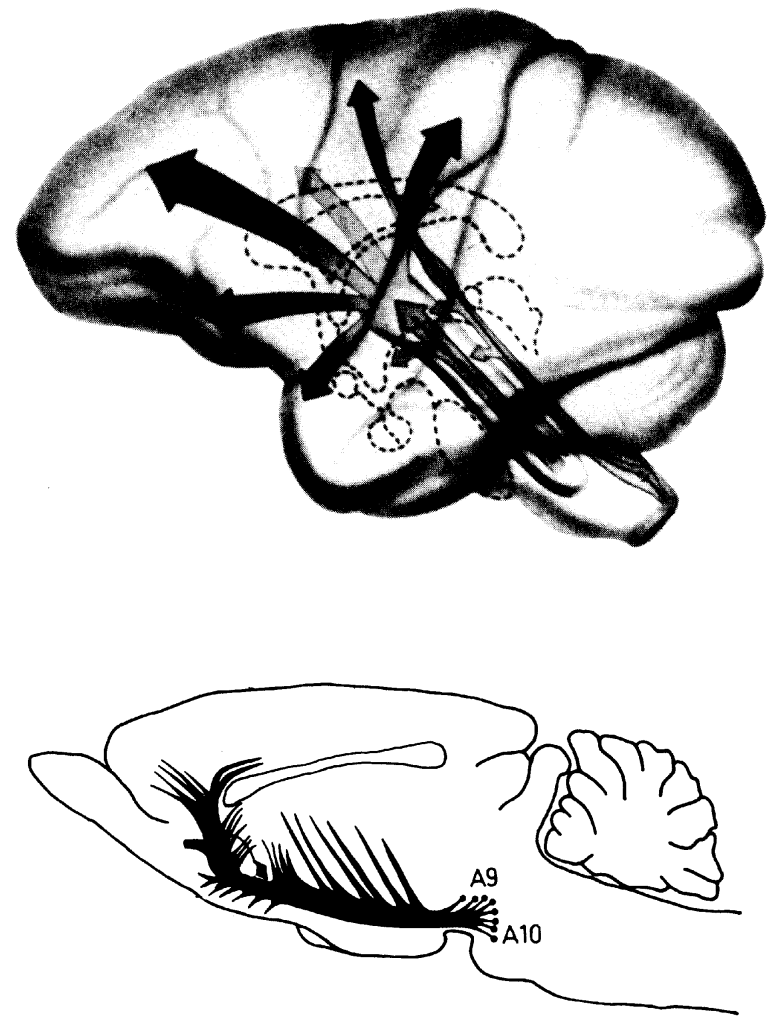


Figure 44. The reticular formation of the brainstem controls global aspects of cerebral functioning. In the 1950s it was thought that the reticular formation was a diffuse set of neurons, as shown in the *upper* figure, which depicts the brain of a monkey. (From H. W. Magoun, 1954.) Today we know that it is, rather, a host of discrete nuclei, which can be distinguished essentially by the neurotransmitter they synthesize. In the brain of a rat, nuclei A9 and A10 are marked to indicate the neurons synthesizing dopamine. (From O. Lindvall and A. Björklund, 1974.) Their axons project to diverse regions of the brain, in particular the frontal cortex (see A.-M. Thierry et al., 1973).

phins and enkephalins, may be involved. The divergent activity of brainstem neurons may thus be mediated by a hormonal effect, with a "bath" of neuropeptides regulating the state of consciousness of the cortex.

How is the cortex awakened or put to sleep by these control systems? One might imagine that during slow-wave sleep the activity of cortical neurons decreases and that it increases again on waking or during the short periods of paradoxical sleep. This is not the case. In 1981 M.S. Livingstone and David Hubel managed to record the same visual-cortex cell in a cat for several hours while the animal was asleep and awake

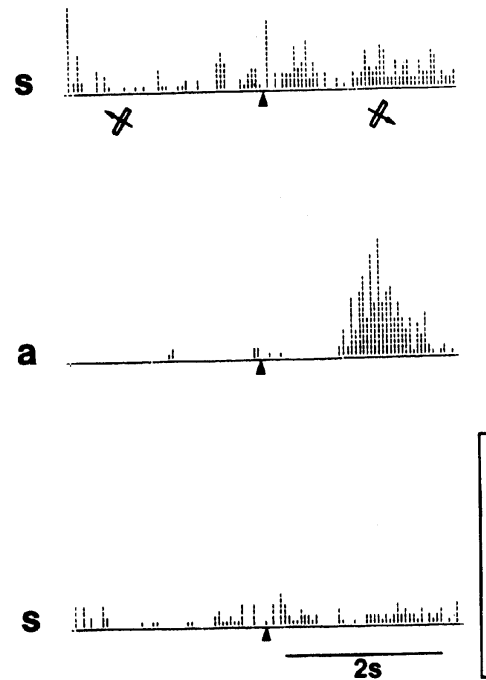


Figure 45. The consequences of waking on the activity of single neurons in the visual cortex of the cat. From *top to bottom*, the recordings were obtained during slow-wave sleep (s), when the cat was awake (a), and once again during slow-wave sleep (s). For each state, the activity of the recorded neuron is represented. Each vertical line indicates the frequencies of the impulses (scale: 100 impulses per second). Waking suppresses the background noise and reveals the neuronal response to the movement of a light stimulus in the direction indicated in the upper figure. (From M. S. Livingstone and D. H. Hubel, 1981.)

(Figure 45). They observed that during slow-wave sleep, neurons were not electrically quiet. On the contrary, they exhibited considerable spontaneous activity, usually in the form of regular bursts coinciding with the peaks of the slow delta waves. Waking caused these bursts to disappear, or desynchronize. It also reduced the frequency of the impulses. Livingstone and Hubel also observed that during slow-wave sleep stimulation of the eye by light evoked a response from visual-cortex neurons. However, the frequency of the recorded impulses was generally lower than in the waking cat; moreover, the spontaneous activity was very pronounced. Waking the cortex thus improves the signal-to-noise ratio; it increases contrast, as if the cells were in a state of quiet wakefulness, preparing themselves for interactions with the outside world and thus assuring each neuron the opportunity to express its own singularities, participate in the formation of conscious percepts, and integrate its activity in an assembly of neurons.

Consciousness, then, corresponds to a regulation of the overall activity of cortical neurons and, more generally, of the entire brain. A few small groups of neurons in the brainstem, with their cell bodies centrally situated, exert a "global" influence, thanks to the divergent nature of their axons. The regulation of states of alertness thus relies on anatomically and chemically simple mechanisms.

ATTENTION

As we saw in the example of hallucinogens, in pathological or artificial circumstances, the production of mental objects may escape the control imposed by one's will. This control is also lost, as is the perceptual component of consciousness, when one falls asleep. The "wholeness" of consciousness breaks down into elementary regulatory mechanisms. Until now we have considered only the formation of images and concepts and their linking together in the alert, awake subject. When one falls asleep, images do not cease; on the contrary, they take on the exuberant forms of the dream, an imaginary and unreal form of thought. Once again the perception of mental objects becomes dissociated from their intentional production.

In 1965, in an attempt to identify objective signs of dreams, William Dement woke sleeping subjects at different EEG stages of sleep and asked if they were dreaming. He found that during paradoxical (or

REM) sleep the majority of replies were positive, but that a considerable number reported dreams during slow-wave sleep. The dreams during slow-wave sleep, however, had a factual content, concerning tax declarations or scientific problems, for example; in other words, they were relatively close to conscious thought. They differed from the dreams of paradoxical sleep, which were filled with vivid images and lively narratives. As with hallucinations, during dreaming, images and concepts form and link together without significant interaction with the outside world, but this imagery develops in the fog of slow-wave sleep and only rarely reaches consciousness. This mental activity, then, belongs to the "non-conscious" or, if one prefers, the unconscious. Nevertheless, to take Sigmund Freud's view that the dream is "the royal road to the unconscious" or the disguised expression of a repressed wish teaches us little about its functions or, even more important, the mechanisms that regulate this spontaneous production of mental objects.

A remarkable experiment performed in 1979 by Michel Jouvet and his colleagues is particularly instructive in this context. The storm of paradoxical sleep is so violent that one might expect it to involve motor centers and consequently cause the sleeping subject to move. In reality, this does not happen. Movements are blocked in the spinal cord at the level of the motor neurons that govern muscular contraction. A specific brainstem nucleus, the locus coeruleus alpha, paralyzes the motor neurons. If it is destroyed, the paradoxical activity is "freed" and can give rise to a behavioral pattern. Imagine that this center is damaged in a cat—will it then show spastic, disordered movements, as if having an epileptic fit? Not at all. On the contrary, Jouvet observed that the sleeping cat manifested organized behavior. It explored its territory, licked and washed itself, attacked an imaginary prey, and showed signs of "anger," but all without any particular logical order. Normal elementary behavioral patterns were thus linked together in a haphazard fashion. Automatic behavior, which we know is controlled by subcortical centers, was observed, but it occurred randomly, without meaningful coordination. The generator of paradoxical activity, which is responsible for this behavior, thus has the role of evoking mental objects and linking them together according to patterns already recorded in the form of stable graphs. But it does not really organize them. Another form of regulation, necessitating that the cat be awake, is essential to link them together in a meaningful behavioral pattern.

The reason for the periodic appearance of paradoxical activity during sleep is not known. It has stimulated many hypotheses. During the course of evolution, development of paradoxical sleep parallels the expansion of the cortex, and it seems reasonable to relate the two. Could paradoxical activity play a role in the way the cerebral cortex treats mental objects? Could it serve to "rehearse" mental objects and patterns so they will not be lost during the night? Could it be responsible for continuing during sleep the stabilization of neuronal graphs begun during the day?

It is a big step from understanding the significance of paradoxical activity in cats to the interpretation of dreams. Obviously, major differences exist between the "exteriorized" behavior of the operated cat and dreams. In particular, the experimental cat never shows signs of sexual activity, which occupies such a large part of our human dreams. And yet, the sequences of unrelated events in our dreams remind us of the apparently random behavioral "collages" of the operated cat. But should we go as far as adopting Jacques Lacan's idea that the dream, like the unconscious, is "structured like a language"? That depends on which language we are talking about—that of a normal person or of a mad one?

As early as 1824, Pierre Cabanis noted that "the way in which the state of sleep produces images perfectly resembles that in which the phantoms of delirium and madness are produced." Some years later, in 1855, M. Moreau de Tours wrote the following memorable phrase: "Madness is the dream of the waking man." In delirious states the intentional and perceptual components of consciousness persist, as in hallucinations, but the "dialogue" with the outside world and with one's self is disturbed. The delirious person pursues an autonomous discourse that, as in a dream, is not directly bound to his interactions with the environment. He is no longer open to persuasion; he is the victim of an inner imagery that replaces his representation of the real world. The conscious control mechanism that normally deals with comparing perceived and conceived objects functions poorly, if at all. An understanding of the organic causes of this state might give us some idea of the essential components of consciousness, but our knowledge is still far too fragmentary to permit definitive answers.

Let us examine some of the features that characterize delirious speech.²⁸ Typically, it is disorganized, with ideas and words strung together in an illogical way. In a single sentence one finds contradictory

themes and words, whose meaning does not fit the context. Concepts are no longer used correctly as tools of reasoning. A *random component* appears in speech and even in the formation of words. There is a clear analogy to Jouvett's operated cat and to the series of images in a dream. But at what level is the disturbance? Is the initial thought disorganized so that the delirious person can no longer compare it with reality, or, on the contrary, does a defect in the ability to compare things make the thought become disorganized? There are probably several answers to this vexing question!

In any case the cerebral comparator no longer functions normally. Comparisons with the outside world use the sense organs for access to essential regulatory mechanisms, particularly *attention*, which manages the relationships of the brain with the environment.

Watch a cat exploring an unfamiliar room. It walks about calmly, looking around, moving its ears from left to right and sniffing. If it finds nothing attractive, it sits down, continuing to look around, before finally falling asleep. Now introduce a mouse in a transparent box: the cat suddenly gets up, turns its head toward the box, raises its ear, and fixes its eyes on the mouse. This is the *orientation* reaction. Both Ivan Pavlov in 1910 and E. N. Sokolov in 1963 described it as the body's first response to any type of stimulus, allowing the animal to use the appropriate analyzing instrument to assure optimal conditions for perceiving the stimulus. If it is a fake mouse, the cat's response will evolve: when we take the mouse away for a few minutes and then put it back, the cat's response is less pronounced than the first time. In the end the cat no longer responds. It will *habituate*. If, however, we now present a real mouse, the cat again reacts as it did the first time. It *dishabituates*. These varied reactions ensure an efficient exploration of the environment. The orientation reaction is used for a first, detailed examination and an initial focusing of attention; the situation is then constantly updated by the cycle of habituation and dishabituation.

The same process obviously applies to humans. We face continual challenges in our everyday life, whether we are crossing a street or listening to a Bach fugue, in which shifting tonalities and voices, subjects and countersubjects, "dishabituate" constantly. This process may not be obvious on the outside, in a particular form of behavior or attitude, but it can be recorded as an EEG trace. As we saw in Chapter 3, when a subject fixes his attention, desynchronized beta waves replace the regular alpha waves. If he habituates, the alpha waves reappear.

But one's attention can be directed more selectively toward a particular sensory modality. Stephen Hillyard and his colleagues recorded the variations in evoked potentials (Chapter 3) in the temporal or occipital regions when the ear was stimulated by a click or the eye by a flash of light.²⁹ The subjects were asked to fix their attention on one eye or one ear just at the moment that the click or the flash appeared. A marked change in the form of the recorded wave was noted depending on whether the subjects fixed their attention on the right or left ear or eye. Fixing the attention increased the amplitude of the principal slow waves significantly. It created a "hyperarousal" of the particular cortical area selected by the subject (Figure 46).

The mechanism for this spotlighting of a particular sensory area has been investigated in the cat at the cellular level. Once again the reticular formation plays a critical role. In 1979 Wolf Singer followed the

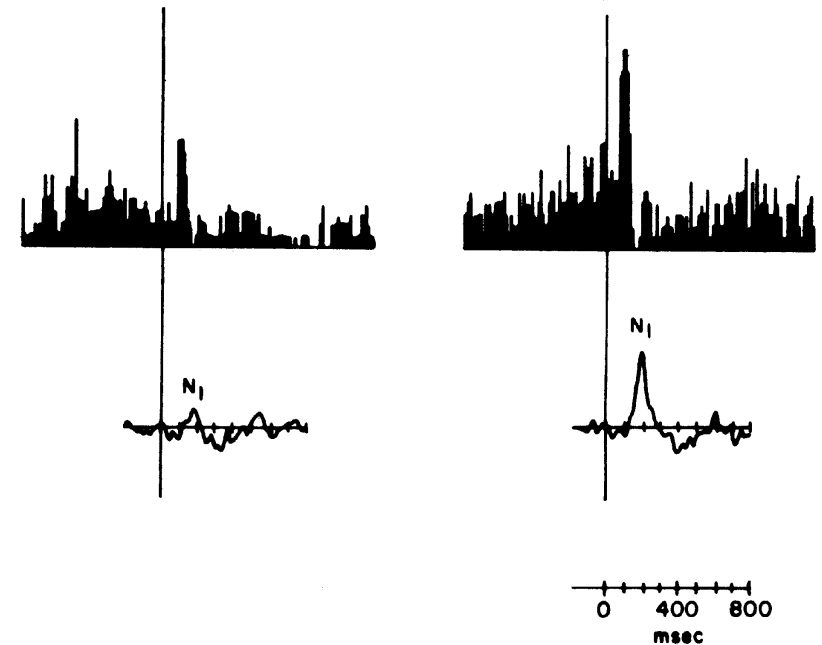


Figure 46. EEG recordings comparing the effects of attention on the activity of individual neurons in the posterior parietal cortex of the monkey (*above*) and on the evoked potentials, recorded at a similar level, in man (*below*) in response to a flash of light. In the recording on the *left*, the subject was inattentive; on the *right*, attentive. Focusing attention increases the amplitude of the evoked response and improves the signal-to-noise ratio. In the upper recordings, the vertical bars indicate the frequency of the impulses. (From R. Galambos and S. A. Hillyard, 1981.)

propagation of electrical impulses in the cat from the optic nerve to the cortex via the thalamus. When the cat was awake, the impulses traveled normally. But if the reticular formation (close to the locus coeruleus alpha, which is responsible for paradoxical sleep) was stimulated just as the impulses were passing, the transfer of the signals to the cortex was markedly facilitated, as judged by a rise in the amplitude of the cortical evoked potential (see Figure 46). This rise results from the removal of an intrinsic inhibition, which makes a given "channel" work at a low yield during rest. Acting as a neurotransmitter, acetylcholine can inhibit an inhibition and thereby activate. The nucleus of the reticular formation that contains this neurotransmitter acts as a regulator of the visual channel.

Nuclei in the reticular formation regulate the passage of sensory messages. They also participate in more global forms of control, such as the orientation reaction and the fixation of attention. A particular nucleus containing dopamine—the A10 nucleus—plays an important role in this respect.³⁰ Let us return to the example of the attentive cat. If the A10 nucleus is removed and a few months later we observe the cat's behavior, we see that it no longer explores a room in its normal calm way.³¹ It goes here and there in all directions, without paying particular attention to details and objects. The cat has completely lost its attentive attitude; it has become hyperactive and is easily distracted. If it is presented with a mouse in a transparent box, instead of remaining still and looking at it, the cat walks around the box without stopping. When a precursor of dopamine, DOPA, or a drug acting like dopamine is injected, this abnormal behavior disappears: the cat becomes calmer and seems more attentive. Thus dopamine neurons in the brainstem are concerned with the control of attention, in addition to their involvement in the "pleasure synapses" that control motivation (see Chapter 4). Like acetylcholine in the visual pathway, dopamine acts as an *inhibitory* neurotransmitter in the cerebral cortex. It is possible that this inhibition in turn affects an inhibitory mechanism, thus leading to facilitation, selectively arousing cortical areas innervated by these neurons. Whatever the situation, the dopamine neurons of the A10 nucleus are involved in regulating the *selective contact* of the brain with the outside world.

This brings us back to delirium. The first psychiatrists to describe schizophrenia, Emil Kraepelin in 1896 and Eugen Bleuler in 1911, already attributed considerable importance to the disturbances in atten-

tion, particularly the orientation of attention, that afflict some of these patients. Recent research has confirmed their point of view.³² When tested, schizophrenics generally reveal significant disturbances in attention. Their reaction times are long and variable. They are easily distracted and their exploration of both the outside world and their own inner world seems slow. Their difficulties with thought and language can also be interpreted as defects in attention, involving both poor selectivity (in that they cannot exclude irrelevant internal or external stimulation) and excessive fixation of attention. Most drugs that attenuate the symptoms of schizophrenia are related to the dopamine receptor.

Clearly the operated cat and the schizophrenic differ in many respects. Malfunctioning of the A10 nucleus in the brainstem cannot alone explain the disease. Nevertheless, this work emphasizes the critical role of the brainstem nuclei as "regulators." Some of the dopamine neurons control the orientation of attention, just as certain acetylcholine neurons control the visual pathway. They exercise a very selective control over exchanges between the brain and the outside world and maintain a permanent dialogue between inner thought processes and the real world outside. Other groups of still poorly identified neurons are concerned in an "internal" focusing of attention on memory images or concepts. One might expect that they impose their rules, their specific "grammar," on operations carried out on mental objects, their linking together, and, of course, their exchange with the environment.

The different groups of neurons in the reticular formation receive signals from the sense organs. They are closely tied to the cranial nerves and have direct access to the outside world. As they know what is going on outside, they can activate or extinguish either large parts of the brain or very precise cortical areas, even particular parts of an area. These brainstem nuclei do not perform detailed analyses. That is the job of the cortex. But they control the pathways that permit this analysis. They act in some ways as "pilots" or, if one prefers, as the console of the cortical "organ," selecting a particular keyboard or set of pipes particularly suited to the formation and treatment of specific mental objects. For this piloting to give the organism the autonomy it needs, the brainstem neurons must themselves be informed of the analysis performed by the cortex on mental objects; indeed, pathways do exist from the cortex to the brainstem. These *reentries* close the loop.³³ A confrontation is possible between the outside world and one's inner world. The regulatory system evaluates resonance and dissonance be-

tween concepts and percepts. It becomes a mechanism for the perception of mental objects, for the surveillance of their linking. The different groups of neurons in the reticular formation inform each other of their mutual activity. They form a system of hierarchical, parallel pathways in permanent *reciprocal* contact with the other structures of the brain. A holistic *integration* between various centers results. From the interplay of these linked regulatory systems, consciousness is born.

THE CALCULATION OF EMOTION

The most fundamental social motivations, according to Harry Harlow, are the different forms of love and affection. Within a social group, emotions are communicated through attitudes, gestures, and, even more important, facial movements, without necessarily having recourse to words. As we saw in Chapter 4, the emotions involve neurons in the hypothalamus and the limbic system, which are important not only for an individual's motivation to look for food or sexual partners, but also for "togetherness." If one accepts Jean-Paul Sartre's view, "emotion is a form of existence of consciousness . . . a state of consciousness." Indeed, emotions are perceived internally by the conscious subject, but percepts elicited from the outside also engender emotions. There is continual traffic between the cerebral cortex, the limbic system, and the hypothalamus.

The involvement of the frontal cortex, the most forward part of the cortex (see Figure 6), in emotional behavior was suggested by an observation dating from the time of Paul Broca. It concerned the famous case of Phineas Gage, a railroad worker in New England, cared for by Dr. John Harlow for many years until his death.³⁴ Gage was twenty-five years old when, while filling a hole in a rock with gunpowder and tamping it with a pointed iron bar, the charge exploded and the bar was blown out. The point penetrated the left angle of his jaw, came out of the top of his skull in the frontal region near the sagittal suture, and was picked up some distance away covered with blood and pieces of brain. Less than an hour after the accident, Gage climbed a staircase and told the story of his accident to a surgeon! He survived for twelve years but with serious behavioral disturbances, which Harlow described very precisely and which still serve as criteria in the diagnosis of lesions of the frontal lobe: "He is fitful, irreverent, indulging at times in the

grossest profanity (which was not previously his custom), manifesting but little deference for his fellows, impatient of restraint or advice when it conflicts with his desires, at times pertinaciously obstinate, yet capricious and vacillating, devising many plans of future operation, which are no sooner arranged than they are abandoned in favor of others that he finds more practical." Since the beginning of the century, other cases of frontal lobe lesions have been reported, and a wide variety of consequences have been noted. The disturbances are either "psychopathic," as in Gage's case, or "depressive." The patient becomes apathetic and indifferent and cannot express his emotions; he speaks little or not at all. It is obvious that the frontal lobe plays a role in regulating emotional states. Its intimate anatomical relationships with the limbic system account for this role.

As the case of Gage shows, lesions of the frontal lobe do not cause only emotional disturbances. There is also a very specific aphasia, due to the fact that Broca's area is situated in the extreme posterior part of the frontal lobe (see Chapter 4 and Figures 6 and 40). Moreover, disturbances of short-term memory occur. The patient "forgets to remember." He is easily distracted and shows difficulty in concentrating, in attention. He also has little appreciation of the past or the future, as can be seen in an inability to formulate projects and to realize them. The frontal lobe is the zone where a large number of cortical areas converge. In particular, many secondary sensory areas project to it, while it projects on noncortical motor centers such as the basal ganglia (see Figure 13). In this way it can intervene in the execution of programmed movements and in their adaptation to external as well as internal events. Lesions of the frontal lobe also cause disturbances in the orientation of an individual toward his own body, his self.

It is a region with many capabilities, participating in the elaboration and execution of the most complex mental activity; "constructive activity, verbal intelligence, discursive thought, and logical reasoning."³⁵ It is exceptionally well developed in humans, in whom it occupies 29 percent of the cortical surface area, compared with only 17 percent in chimpanzees and 7 percent in dogs (see Figure 6). To use the terms introduced in the theoretical part of this chapter, mental objects are linked and combined in the frontal lobe, and "programs" of motor action and representations of the space in which future movements will be carried out are constructed. *Intentions* are built up and "materialize" as images or concepts, themselves "composites" of other images

or concepts involving strategies for future behavior. The frontal cortex is an “organ of civilization”—calculating, anticipating, foreseeing.

This anticipatory function has recently been demonstrated at the cellular level in the monkey. The demonstration was based on a relatively simple learning test, developed by C. Jacobsen for the chimpanzee: the “delayed-response” task.³⁶ One puts two identical overturned bowls in front of an alert monkey. A piece of apple is placed under one of the bowls, but the monkey cannot reach it. A few seconds or minutes later, the monkey is allowed to choose one of the overturned bowls. If, on its first attempt, it indicates the bowl under which the apple is hidden, the response is considered positive and the monkey is allowed to eat the apple. Obviously from one trial to another the apple is placed randomly under either bowl. After a few trials the monkey learns to give the correct answer regularly. Jacobsen showed that removing the frontal lobe caused a major deficit in the performance of this test. In the light of these results, in 1980 J. M. Fuster recorded electrical activity of single neurons in the frontal lobe of a macaque while the delayed-response test was being performed. He distinguished several types of cellular response. Some neurons were active upon presentation of the bowls, or during the execution of the response. Others discharged impulses during the entire experiment. The most interesting neurons were less active during the presentation of the stimulus and the execution of the response but showed a marked increase in discharge rate *during the intervening delay*. They did not respond if the bowls were presented again without the apple, if the monkey had not learned the task, or if it was distracted during the task. The response of these neurons is therefore related to the storage of visual information and to the elaboration of an appropriate motor act. It is true that only a small number of the total neurons in the frontal lobe behave in this way. Yet the simple fact that they *can* be recorded by an electrode passing through the cortex suggests that they are not rare. A neurophysiological model of anticipation becomes possible.

To return to patients with lesions of the frontal lobe. Almost all, A. R. Luria indicated in 1978, suffer from an appreciable reduction of their critical faculties: they cannot correctly evaluate their behavior or judge their own actions. The role of the brain as a comparator necessitates that the frontal lobe be intact. We have already emphasized the importance of the role played by attention in the constant dialogue between the brain and the outside world, whether physical or social.

It is no great surprise to find that the frontal cortex is greatly influenced by the dopamine, A10 nucleus in the brainstem, which, as we have seen, is involved in regulating attention. A rat, in which this nucleus has been removed, fails the delayed-response test, as if the frontal lobe were missing. The A10 nucleus, then, acts as a “regulator” of the frontal lobe. It permits the internal focusing of attention on this brain area and allows it to act as a comparator.

The immediate result of comparison, in the terms of our theoretical discussion, is to bring out the resonance and dissonance between mental objects. What will the consequences be? It has already been emphasized that lesions of the frontal lobe cause both emotional and cognitive disturbances. Even if different, though overlapping, parts of the lobe are preferentially engaged in one or the other of these behaviors, they may become linked or “associated” at the cortical level. One might envisage that resonance between mental objects on the cognitive plane is communicated to the neighboring emotional part of the frontal cortex, releasing bursts of impulses that travel to the limbic system and the hypothalamus with a consequent pleasurable effect—or, if there is dissonance, a depressive effect. It becomes easy to understand the seriousness of the emotional disturbances that a delirious person will suffer if such resonance is missing or inadequate. One can also understand how a single word could evoke resonance or dissonance with a memory image, thus provoking joy or distress.

The dialogue between the cortex and the limbic system and hypothalamus does not always end in the same way. Resonance between rational concepts is pleasurable, but as Blaise Pascal said, “the heart has its reasons that reason does not know.” In other words, the limbic system and the hypothalamus (together, the “heart”) have enough autonomy vis-à-vis the cortex that, under the pressure of particularly strong sensory stimulation, motivation may increase to such an extent that the subject “goes into action” even if the cortical resonance (“reason”) says “no” to the act in question.

SEEING MENTAL OBJECTS

Emotions are transmitted from one individual to another by facial expressions or bodily gestures. The conceptual or imagistic content of this communication is, however, limited. No television transmits men-

tal concepts or images directly from one brain to another! Communication of mental objects is usually accomplished through the symbols of language, a heavy and cumbersome coding system, not necessarily well adapted to the "language of thought."

The organization of the cortex reflects the difficulty of communicating mental objects from one individual to another with the means at our disposal, with the mouth, ears, hands, and eyes. As we saw in Chapter 4, the left hemisphere governs the spoken language. But as John Hughlings Jackson wrote in 1868, "the two brains cannot simply be double." Patients with Broca's aphasia sing quite well, but lesions in the right hemisphere have been described as causing professional musicians to lose their ability to perceive and produce music. Lesions of the right hemisphere are also accompanied by major defects in tests of mental imagery, such as those described at the beginning of this chapter.

The specialization of each hemisphere in different communications tasks is also illustrated by the well-known studies of Roger Sperry on patients in whom the *corpus callosum*, the fiber bundle that unites the two hemispheres, had been cut.³⁷ After this operation, both hemispheres remain connected to the sense organs, but, because half the fibers in each optic nerve cross, the right hemisphere sees the left half of the visual field and the left hemisphere the right half. It is thus possible to communicate separately with each hemisphere. Sperry asked N.G., a California housewife, to tell him what she saw on a screen, which was divided vertically down the middle and upon which different images were projected on the left and right sides. He asked her to fixate a point in the middle of the screen. When a picture of a cup was presented on the right, she replied, "I saw a cup." When a spoon was projected on the left half of the screen, she replied that she had seen nothing. Yet, with her left hand, she chose a spoon from a pile of objects in order to indicate what she had seen. When she was asked to name the object in her hand, she said, "Pencil." The dialogue continued. A photograph of a naked woman was projected on the left of the screen. She blushed a little and laughed behind her hand. "What did you see?" asked Sperry. "Nothing, just a flash of light," she replied. "Why are you laughing, then?" "Oh, doctor, you have some machine!" The patient was capable of verbally naming an object (like the cup) presented in the right visual field, and therefore to the left hemisphere. She was not able to name an image presented to the right hemisphere.

Nevertheless, she recognized the spoon and reacted emotionally to the photograph of the naked woman. The right hemisphere analyzes and produces images whereas the left hemisphere is specialized in verbal and abstract operations.

Let us reconsider the theoretical notions discussed at the beginning of this chapter. Various results suggest that mental objects with a realistic component, like pictures, preferentially mobilize neurons in the right hemisphere, while those with a more verbal or abstract content—concepts—recruit neurons in the left hemisphere. This conclusion is, however, relative, for each hemisphere contains functional sensory areas. For example, the visual areas of *both* hemispheres contribute to the vision of an object in space and thus to the formation of a spatial percept. Assemblies of neurons working in cooperation must then be distributed through both hemispheres. Their interrelationship is possible through the 200 million, or more, axons of the corpus callosum. The continual to and fro of percepts and concepts might then correspond to a right-left oscillation. This recruitment of masses of active neurons is accompanied—for the "logic" of linkages and for their emotional charge—by "movements" in another direction: with the involvement of the frontal lobes, the activity of assemblies of neurons will swing back and forth from the front to the back of the brain.

These movements in the activity of large groups of neurons are not purely imaginary. Recent advances in the techniques used to explore the brain, whose full impact is still unknown, already permit us to "see" these movements through the skull. The technique is based on a visualization of the energy expenditure that results from nervous activity. As we saw in Chapter 3, the production of an electrical impulse uses energy, resulting in an increased consumption of glucose, the basic source of energy in the body. The metabolism of glucose produces carbon dioxide, which, when released, acidifies the blood and causes the capillaries to dilate. As the overall circulation increases, more blood flows in the tiny blood vessels around active neurons.³⁸ In the skin one sees this as a reddening. In the cerebral cortex a local increase in blood flow cannot be seen unless one has a way to "see through" the tissues, and particularly the skull. Such a technique is available: positron-emission tomography, or *PET scanning*, which uses radioactive isotopes. When injected in the blood traveling to the brain, these isotopes serve as markers of blood flow, which is directly related to brain activity.

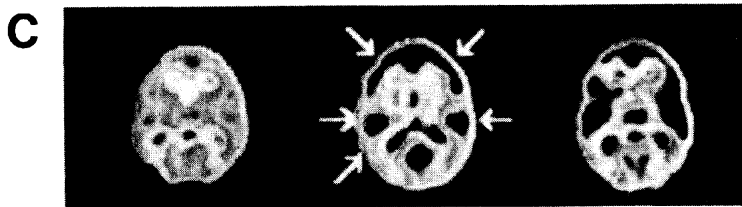
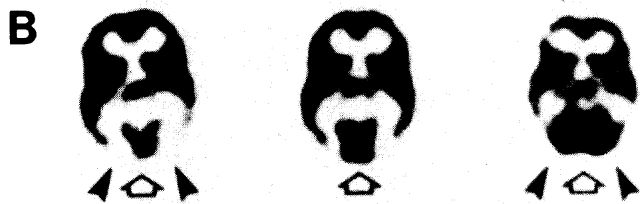


Figure 47. “Internal” states of activity of the human brain observed through the skull by PET scanning, using a positron camera and the radioactive tracer ^{18}F -fluorodeoxyglucose. In *A*, the subject has his eyes closed (on the *left*), then opens them (on the *right*). The visual cortex in the occipital lobe “lights up” (arrows). (From a color photograph by M. E. Phelps et al., 1981.)

B shows the effect of the complexity of the visual scene on the activity of the visual cortex (arrows). On the *left*, the subject has his eyes closed; in the *center*, they are open but see only a uniform white background; on the *right*, the subject is looking at a wooded park near the laboratory. In this photograph, the intensity of the black is directly proportional to activity. (From M. E. Phelps et al., 1982.)

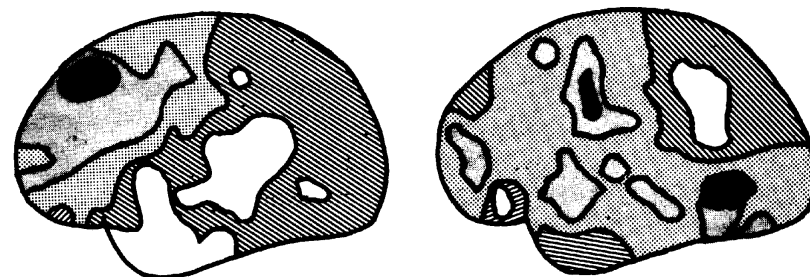


Figure 48. Differences in cerebral blood flow indicated by a positron camera (using the radioactive isotope Xenon 133) in a normal subject without any obvious mental disturbance (*left*) and in a schizophrenic patient (*right*). At rest the radioactive landscape shows a relative hyperactivity in the frontal lobes (in black) in the normal subject, which is not found in the schizophrenic patient. (From D. H. Ingvar, 1982.)

They cause, not an actual reddening, but a radiation, visible to a camera sensitive to gamma rays (Figures 47 and 48).

The isotopes used (xenon 133, carbon 11, or fluorine 18) do not themselves give off gamma rays. Rather, they emit positively charged particles—*positrons*—which travel over distances of a few millimeters before colliding with a negative electron. There is then a tiny “explosion,” releasing two photons, or particles of light, that fly off in opposite directions. The camera used detects these two photons simultaneously, thanks to a battery of photosensitive cells around the object under study, in this case a person’s skull. A computer connected to the camera performs a series of triangulations to locate the point at which the photons were emitted. The results are represented point by point on a video screen as a two-dimensional image. The regions that are richest in isotopes appear brightest on successive computer “slices” of the brain. They represent areas of greatest blood flow, that is, those with the highest metabolism and therefore the greatest electrical activity. The positron camera allows us to see the state of activity of neurons inside the skull. In this light, David Ingvar in 1977 called this technique *ideography*.

As this is a very recent technique, it still has severe limitations. First of all, in space. The blood capillary network is much larger than a nerve

C shows the effect of auditory stimulation. On the *left*, the subject’s ears are blocked; in the *center*, he is listening to a Sherlock Holmes story, and, on the *right*, to one of the Brandenburg concertos by Johann Sebastian Bach! There is increased activity in both the temporal lobes, where the auditory cortex is situated, in the frontal lobes. (From a color photograph by J. C. Mazziotta et al., 1982.)

NB: When black and white reproductions are made from color photographs, there is no linear relationship between the intensity of the black and the activity.

cell. Measures of the local blood flow cannot attain the resolution of a single neuron. For this reason other procedures have been developed. For instance, in 1977 Louis Sokoloff and his colleagues demonstrated that deoxyglucose, a molecule closely related to glucose, is taken up by active cells. Unlike glucose it is not burned up by cell metabolism, but accumulates inside a neuron. In theory, it should permit us to follow the state of activity of a single neuron. When tagged with fluorine 18 and studied with a positron camera it gives splendid pictures (see Figure 47). Unfortunately, the positron travels a few millimeters before producing the two photons. There is thus an unavoidable "graininess" to the PET scan pictures; their resolution is poor, no better than a square centimeter. Time factors also impose limits on such analyses. The radioactively labeled substances used take some time to reach the nerve tissue and accumulate in large-enough quantities for maximum contrast. The recording and the computer analysis also take time. To obtain a readable image by PET scanning still requires several minutes.

Nevertheless, amazing results have already been reported. A proof of the validity of the method is that the "radioactive landscape" is different when subjects are awake and when their level of consciousness is reduced. The alert state is characterized by a higher blood flow or glucose metabolism in the frontal cortex than in the rest of the cerebral cortex: a *hyperfrontal* distribution. When consciousness is lost, this difference diminishes or disappears.

The stimulation of a particular sense organ causes an accumulation of the radioactive tracer in the related sensory area. In the case of vision, in 1981 and 1982, M. E. Phelps and his collaborators noticed marked differences in the distribution of deoxyglucose in the cortex depending on the scene before the subject. If the eye was stimulated with white light, the main response involved the primary visual cortex (area 17). On the other hand, when the subject looked at a checkerboard of black and white squares, there was a greater accumulation in area 17 but also activity in the secondary visual areas 18 and 19. Furthermore, if the subject looked at a complex environment, such as the wooded park around the laboratory, the intensity of the reaction was even greater in both primary and secondary areas. These results reinforce the idea, put forward at the beginning of this chapter, that the formation of a visual percept involves secondary areas as well as the primary visual cortex.

In 1982 Ingvar also showed that when a subject speaks, the blood flow increases in the parts of the motor cortex devoted to the mouth and in the auditory cortex. This is most marked in, although not exclusive to, the left hemisphere. A purely mental activity, one with neither sensory stimulation nor motor activity, changes the radioactive landscape of the cortex with the blood flow increasing particularly, as we might expect, in the frontal lobe.

Studies in three different laboratories in the United States and Sweden have revealed a clear difference in the distribution of blood flow in normal subjects and chronic schizophrenics. In the latter, no hyperfrontal activity is seen; blood flow in the frontal cortex is quite low. Rather, there is a *hypofrontal* distribution, with peaks of activity in the temporal and parietal regions. One possible interpretation is that schizophrenics have a dormant frontal cortex, but they also exhibit other anomalies (see Figure 48).

PET scanning allows us to study the internal functioning of the brain. Its clinical applications are already of great importance. Temporal and spatial resolution, although still poor, will probably improve in the future. Other methods are being developed. It is not overly optimistic to envisage one day the appearance on the screen of the image of a mental object.

One essential question, however, remains. PET scans reveal states of activity in groups of neurons. Can one find the trace, or *engram*, that persists between two evocations of a mental image? Is there a cerebral "organ" that preserves some elements of an image as the seed for the development of cooperation within the neuronal assembly? Or, on the other hand, does the entire cerebral cortex participate in the storage of mental objects? Certain cerebral lesions in humans selectively affect the use of memory. The temporal lobe and the "old" cortex, the hippocampus, certainly play a role. There is, however, no proof that the engram is localized in either. Indeed, is their tiny surface area sufficient to account for the huge capacity of human memory? In harmony with our conclusions about the genesis and stabilization of assemblies of neurons, it seems, on the contrary, more reasonable to envisage the memory trace as spread throughout the cortex and maybe even through a large part of the rest of the brain. As Keith Oatley wrote in 1978: "The ability to learn is a fundamental property of the nervous system of mammals which is not limited to one of its parts."

THE SUBSTANCE OF THE SPIRIT

The theme of this chapter—to destroy the barriers that separate the neural from the mental and construct a bridge, however fragile, allowing us to cross from one to the other—carries great risks and can be criticized. It is based on relating mental activity to states of physical activity in neuronal assemblies. The term “mental objects”—used as the title of this chapter—concretizes this notion by pairing the noun “object” with the adjective “mental.” The main risks are oversimplification, failure to account for all mental processes, and partiality. Certainly, the experimental data are still too fragmentary for us to go much further. Indeed, the problem is not to explain everything, but rather to place a ladder against the wall of this mental Bastille. “Spiritualistic” alternatives have often been put forward. In contrast to these, the interpretation here is open to experiment and will, it is hoped, stimulate research.

The proposed hypothesis, or model, has the advantage of taking into consideration both psychological information and data gathered from anatomical observations and physical measurement, whether electrophysiological or chemical. This explains the continual back and forth in this chapter between what one might call the subjective and the objective. Such an effort is open to criticism of its methodology, unless one day—a day I hope is close—it leads to real progress in our knowledge of the brain and its functions.

The concept of assemblies or cooperative groups of neurons leads directly from one level of organization to another, from the individual neuron to a population of neurons. The number of neurons engaged in the graph of a mental object is not known: hundreds of thousands, millions maybe. It is conceivable that these assemblies possess some kind of autonomy, and that within them new properties can appear, explicable in terms of intrinsic properties of the neurons—just as the properties of a molecule can be explained on the basis of those of its atoms. Clearly identified synaptic and molecular mechanisms make such assemblies of neurons quite plausible, for individual neurons can easily be integrated into larger units that permit passage from one level to another.

The correlated states of activity that make up the graph of a mental object have not yet been measured. Only states of activity of cortical regions or of generalized parts of the human brain have been observed with the positron camera. But I have high hopes that this technique,

or others in the future, will allow us to follow mental objects themselves in spite of their fleetingness and their dispersion throughout the brain.

To do this, it will be necessary to identify large populations of neurons distributed over wide regions of the cortex and probably other parts of the brain. Those mental objects that are images will probably be derived partly from the homunculi in the primary or secondary sensory areas; those that are concepts, from the association areas, such as the frontal cortex, that have no particular sensory or motor bent. The figurative or abstract nature of these representations will thus depend on the proportions of neurons involved that are in preexisting cortical homunculi, compared with the proportion of cells in other cortical areas. The neurons participating in assemblies of concepts will be both dispersed and multimodal, or perhaps amodal. This should bestow on them very rich “associative” properties, allowing them to link together and above all to combine. Thus, it becomes plausible that such assemblies, made up of oscillatory neurons with high *spontaneous* activity, could recombine among themselves. This recombining activity would represent a “generator of hypotheses,” a mechanism of diversification essential for the genesis of pre-representations and subsequent selection of new concepts. In a word, it would be the substrate of imagination. It would also account for the “simulation” of future behavior in the face of a new situation. In order for a system to organize itself, it is obvious that there must be more than simple creation of diversity. A *selection* is possible, as we have seen, by the comparison of mental objects in terms of their resonance or dissonance.

Operations on mental objects, and above all their results, will be “perceived” by a *surveillance system*, composed of very divergent neurons (such as those in the brainstem) and their reentries. The existence of regulatory loops with reentries at several organizational levels of the brain could lead to high-amplitude oscillations. (The alternation of mania and depression and the periodic appearance of delirious states characteristic of certain mental disturbances could be explained in this way.) These linkages and relationships, these “spider’s webs,” this regulatory system would function *as a whole*. Can one say that consciousness emerges from all this? Yes, if one takes the word “emerge” literally, as an iceberg emerges from the water. But it is sufficient to say that consciousness *is* the functioning of this regulatory system. Man no longer has a need for the “Spirit”; it is enough for him to be Neuronal Man.