CHAPTER 3

The Frontal Lobes

The frontal lobes of the cerebral cortex are traditionally considered to be the seat of the "highest" mental functions and the center of those activities that make us characteristically human. This is largely because in evolutionary terms the frontal cortex has been the most recent to evolve, and humans happen to possess particularly large frontal lobes. However, it may also be that because of the relative difficulty of ascribing a clear set of functions to these areas, they have been attributed with intelligence by default. The large proportion of the cerebral cortex described as frontal lobe, up to about half of the total area of the cortex and an even higher proportion of the association cortex, makes it likely that significant aspects of intellectual activity are performed there, but, as we shall see, it is necessary to be a little more cautious about what functions we can with confidence ascribe to this region, which nonetheless remains one of the most interesting for neuropsychologists.

SOME METHODOLOGICAL ISSUES

Before considering just what aspects of intelligence may be associated with the frontal lobes, some points must be made about the specific problems that arise in carrying out research studies on the effects of focal damage to the cerebral cortex. These problems appear because we have to work with clinical material, which does not arise in a random way, and the points made here therefore apply not only to this chapter, but to all the chapters in this section on clinical studies. The logic of the

research design is to collect cases in which there is an identified lesion of some area, let us say in the frontal lobes, and to compare the performance of these patients with the performance of patients who have lesions in areas outside the frontal lobes. This determines whether the functions being studied are affected only by frontal lesions.

However, the essential point is that we have to control in some way for all the factors apart from the site of the damage that could contribute to any deficit observed in performance. These other factors include the type of lesion: what caused it, whether it is developing ("progressive") or stable ("static"), and whether it was recently caused ("acute") or is long-standing ("chronic"). For example, tumors are usually progressive, and may develop slowly or rapidly depending on type, while a gunshot wound can be considered, after the initial period following the injury, to be static. The age of the patient is also important, as is the extent or "mass" of the lesion and how far it extends below the cortex into subcortical tissue.

The main problem is that lesions of different types tend to occur in different areas, and in patients of different ages. Tumors of certain types grow in particular sorts of tissue, but may be fairly evenly distributed across age groups, while missile wounds obviously occur most frequently in young males injured during war or urban violence. Vascular accidents, in which either the blood supply to some region of the cortex is lost (as in a stroke) or some failure results in bleeding into the brain, tend to occur more commonly in older subjects. Studies that compare lesions of the frontal and parietal regions without controlling for the type of lesion may then end up by confounding the site of the lesion with its cause.

Even if the study is restricted to a comparison of lesions of one particular type, for example those caused by gunshot wounds, the lesions occurring at less usual sites may be in some way atypical. Wounds from modern high-velocity projectiles yield perhaps the best clinical material for the neuropsychologist, for the bullet, if not at close range, tends to punch a very neat hole straight through the head, causing remarkably little disturbance to regions not immediately affected, and producing a clean wound that is self-sterilized and cauterized by the heat generated as the bullet passes through. In such cases, the important issue for survival is whether the bullet passes through important central subcortical centers essential to life or fundamental aspects of behavior. If the entry and exit points are around the temporal and parietal regions, death is much more likely than if they are in the frontal and occipital regions. As a result, more soldiers arrive for neuropsychological assessment with frontal or occipital wounds than with temporal and parietal wounds, and the lesions of those with temporal and parietal injuries who do sur-

vive may be less extensive than those of their colleagues and, in a variety of ways, less serious.

An alternative example is studies that examine differences between the left and right members of a particular pair of lobes. Here the confounded variable may be the mass of the lesion. Someone with a developing tumor in the left or right frontal lobe will sooner or later notice some of its effects and will probably consult his or her general practitioner (GP). However, because of the much greater importance of verbal as opposed to spatial abilities in everyday life in our society, these patient are more likely to notice that they cannot remember the contents of the day's paper or an address just given to them, than that they cannot remember some drawing or route to be taken to a particular place. Since the failure in verbal memory usually results from a left lesion and in spatial memory from a right lesion, patients typically arrive for surgery with smaller tumors in the left than in the right hemisphere, where they have been allowed to grow unnoticed for longer. This can naturally confound the results of any study that compares the effects of tumors in the left and right sides of the head, because any differences found may not be due to the lateral site of the tumor but due to the mass of the lesion.

These examples illustrate the considerable difficulty of constructing sound scientific studies when it is necessary to work with incidentally occurring clinical material. The ideal study would involve equal amounts of the same kind of damage occurring in each cortical area, but the data are just not available for such a study. There are additional problems in that it is often assumed that the deficits observed are a reflection of more specific deficits in complex tasks that involve several basic unitary functions in their performance. The factors that contribute to methodological difficulties are summarized in Table 3.1.

It should also be realized that studies of the highest methodological standard are rather uncommon, owing to deficiencies in design and theoretical interpretation, and that many of the findings reported below are

TABLE 3.1. Methodological Difficulties in Interpreting Clinical Lesion Studies

1. Variations in:	site	lobe or region
	lateralization	left/right hemisphere
	extent	mass
	cause	
	age of patient	
	stability	progressive/static
	acuteness	acute/chronic
2. Inferring unitary deficits from performance on complex tasks		

subject to difficulties of interpretation that follow from research problems of the type just described.

INTELLIGENCE

From the latter part of the 19th century the frontal lobes have been associated with intelligent abilities, but a controversy raged through much of the 20th century as to whether these abilities may be associated exclusively with the frontal lobes. It may simply be that the frontal lobes are large, subserve many functions, and are as a result likely to affect "intelligent" behavior more than other lobes of the brain. Alternatively, there may be some general factors such as attention, or motivation, associated with the frontal lobes that have an impact upon all "intelligent" tasks. (Many psychologists would in any case say that "intelligence" is no more than the abilities that determine performance on intelligence tests.) To evaluate the arguments presented in this controversy, it is important to distinguish between quantitative and qualitative changes in intelligence.

In terms of quantitative deficits in intelligence, case reports from the beginning of the 20th century reported reduced intelligence following frontal lesions, and these findings were largely confirmed by the first important research studies by Rylander in 1939 and Halstead in 1940. The finding was simply that measured general intelligence was reduced after damage to the frontal lobes. The view was expressed most clearly in Halstead's description of "biological intelligence" in 1947. He had formulated this concept from the results of a statistical analysis of a battery of tests that had been administered to a large sample of subjects with various focal cortical lesions. Among these tests, and showing the highest "loading" on biological intelligence, was the Category Test, which is a test of concept formation or categorization in which sets of graphical items are presented, and the patient has to indicate which of the numbers 1 to 4 may be associated with the set from the other three (see Figure 3.1). Patients with frontal lobe damage do badly on this test.

Although Halstead's theory commanded much support through the 1940s and 1950s, it was criticized by Hebb, who, largely by studying the effects of deliberately placed experimental lesions in animals on abilities such as maze learning, argued that the mass of the lesion was more significant than its location. This view was confirmed in 1959 by Chapman and Wolff, who performed a reanalysis of much of Halstead's data, introducing the factor of lesion size and adding new data of their own, and found that Halstead's findings could be interpreted in terms of the effect of the mass of the lesion.

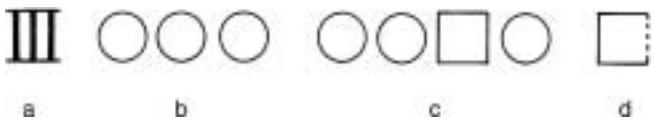

FIGURE 3.1. Examples of four items presented in four subtests of the Halstead Category Test. In each case the correct response would be to press the button marked "3."

During the 1950s and 1960s Teuber, with colleagues, carried out an impressive series of studies on the war injured, which again tended to emphasize that deficits in general intelligence are not exclusively associated with frontal lesions, and that not all frontal lesions produce deficits of this type. The majority of recent studies, particularly those that have been careful in their experimental design, have supported this view, and a good example is the study of Black (1976) on veterans from the war in Southeast Asia. Even studies based on the modern version of Halstead's own battery, developed by Reitan (see Reitan & Davison, 1974, and p. 325, of this volume), and including such tests as the Category Test, do not support the idea that "biological intelligence" is a property of the frontal lobes. There is therefore no good evidence to support the association of the degree of intelligence with the frontal lobes. But do frontal lobe injuries affect the quality or form of intellectual performance?

The change in the quality of thinking most commonly linked with the frontal lobes is the loss of *abstract thought*. This change, or the loss of the "abstract attitude," is linked with the name of Kurt Goldstein, who published his ideas between 1936 and 1959. Goldstein considered there to be two forms of thinking: "concrete" and "abstract." The abstract form was characterized by the ability to assume mental sets, to consider different aspects of a given situation, to dissect and synthesize the elements of some object, and to plan ahead and think symbolically; the concrete "attitude" was tied to the immediate sensory data that could be derived from the object. He employed a battery of tests that included various sorting tasks and a block design task in which colored blocks had to be arranged to match some design presented to the subject (see Figure 3.6 on p. 57). Goldstein claimed to demonstrate that frontal lobe lesions impaired the ability to adopt the abstract attitude, and thereby also caused a decline in conventionally measured intelligence. It should be noted, however, that Goldstein's own work was not based upon the quantitative results of performance in his tests of abstract thinking. He did not, for example, present any quantitative data upon which a discrimination between frontal and more posterior lesions could be based. His arguments rested essentially upon the nature of qualitative

changes, despite the fact that they could be seen as providing the explanation for the quantitative changes in intelligence observed by some investigators.

The difficulty in assessing Goldstein's views arises from both general theoretical and specific methodological problems. The theoretical problem is with the formulation of abstract thinking and its distinction from concrete forms of thought. For instance, some researchers take the copying of a block design in the same color as a concrete task, and the copying of it in a different color as an abstract task. Others, in demanding a definition of the proverb "The sun shines upon all alike," would take "The sun shines on everybody" as a concrete response, and "All men are created equal" as an abstract response. The meaning of "abstractness" is clearly different in these two examples; the definition of this concept is a general problem in psychology. There is insufficient space to discuss this topic sensibly here, but few psychologists currently would accept the views implied in Goldstein's theoretical formulations.

The methodological problem arises from the nature of the tests used to assess the abstract attitude. Because the performance of subjects was not observed, recorded, scored, and analyzed according to the standards that we would now consider appropriate for the administration and interpretation of clinical tests, some doubt is cast upon the data collected by their application. The expectations of the examiner may have played some part in determining the results of Goldstein's tests, and it is known that their formal reliability (that is, the degree to which they yield stable and replicable measures) is unacceptably low. Normative data, by which the test results may be interpreted, are either not available or inadequate. For these reasons, the results of the tests of abstract thinking are not generally acceptable. It is also now clear that patients with posterior (nonfrontal) lesions may also fail on these tests.

In conclusion, it is fair to say that there may be qualitative changes in thinking following frontal lobe lesions but the data and arguments presented by Goldstein are not adequate evidence for such changes. It seems more profitable to inquire why patients may fail on certain tests, and to look at more specific deficits to provide a better explanation of the general difficulties experienced by frontal lobe patients.

The concept of impairment in abstract thinking is very important historically but it also continues to play a role in current theories of frontal lobe function. The idea that the frontal lobes are associated with underlying general intelligence persists. Duncan et al. (2000), taking account of the historical problems in investigations of this kind, argued that *g*, the general factor relating to intelligence that can be extracted from factor analyses of cognitive tests, is specifically associated with

frontal lobe function, and that a specific frontal system underpins the control of a broad variety of forms of behavior.

SPECIFIC FUNCTIONS

If we reject the idea that general aspects of intelligence can be specifically linked to the frontal lobes, then what specific aspects of behavior are controlled by them? There are, indeed, a variety of behavioral components that are affected by frontal lesions, but lacking any clear theory of the logical relationships among all these components (although some theories relating to regions of frontal lobe function are presented shortly), it seems sensible to discuss the frontal lobes by dividing them into four regions, and to treat these separately. It must be emphasized that the division into these four regions, and the association of specific behaviors with each region, is not at all clear-cut, but is a way of making sense of a rather bewildering collection of data.

The four divisions, shown in Figure 3.2, are the motor and premotor cortex; the prefrontal cortex (sometimes referred to as "frontal granular cortex" because of the type of cells predominant in this area, or as *dorsolateral* cortex); Broca's area, which we assume to exist in the left frontal lobe only (at least for the right-handed—see Chapters 7 and 14); and the orbital (or *orbitofrontal*) cortex. We will examine the effects of lesions of each of these regions in turn.

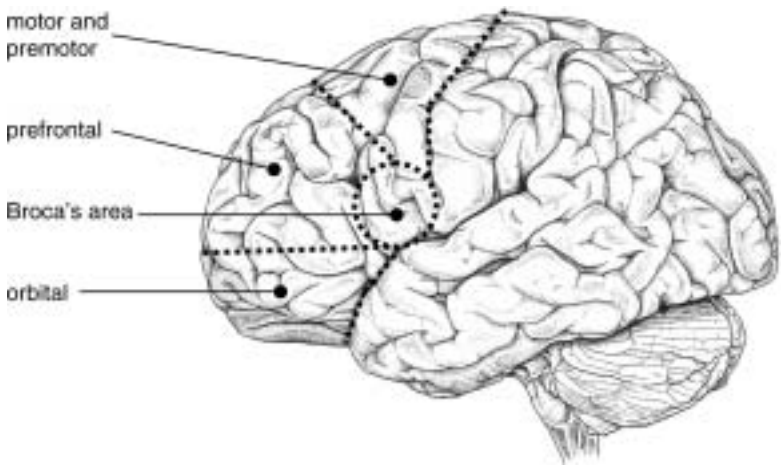

FIGURE 3.2. The four main divisions of the cortex of the frontal lobe.

THE MOTOR AND PREMOTOR CORTEX

When the organization of the cerebral cortex was introduced in Chapter 2, the model of three levels of control, of decreasing specificity and increasing integration, was suggested: primary, secondary, and tertiary. The frontal lobe control of motor function provides a clear illustration of the model.

The primary region is the *motor cortex*, or "motor strip," which has already been described. As cells in this region connect directly with spinal motor neurons and motor nuclei in the cranial nerves, focal lesions of a specific area will lead to a loss of voluntary control over the precise area of the body that is "mapped" onto that area of the motor cortex. The general arrangement of this mapping in the form of an homunculus was illustrated in Figure 2.9. Although there is variation among individuals, the mapping is sufficiently precise for it to have been proposed, and demonstrated as a practical proposition (Prochazka, Mushahwar, & McCreery, 2001), that a prosthesis for spinal injuries might operate by picking up the signals that originate in the motor cortex and relaying them by wiring and a computer interface, past the damage in the spine, directly to the point at which they should be fed into the peripheral nervous system and on to the muscles (or to an artificial limb). Damage to the motor cortex results in chronic deficits in fine motor control, which may be seen most clearly in movements of the hands, fingers, and face, and in a reduction in the speed and strength of limb movements.

Adjacent and anterior to the motor cortex, the *premotor* cortex forms the *secondary level of motor control.* Cells in this region contribute to motor control by forming connections in various subcortical centers, particularly in the basal ganglia, and there seem to be distinct systems for limb movements and for whole body movements. Because the control is exerted by influencing the operation of these lower centers, the effects of lesions of this region are less specific and more subtle, for the basic aspects of control are still being carried out by centers in the basal ganglia, the thalamus, and elsewhere. In particular, lesions of the premotor cortex (with some contribution from parietal cortex) seem to impair the way in which separate movements of the limbs, the hands, and gross body movements are integrated into fluid sequences of action.

Among the signs of lesions of this region, apart from the specific effects on particular limb movements, are some changes of a reflex kind. In *gegenhalten*, which literally means "counterpull," there is an involuntary resistance to movement, so that if the forearm, held in a certain

position quite loosely, is moved by the examiner, a marked resistance preventing movement of the limb may develop unintentionally. Similarly, there may be an involuntary grasp of a hand or object placed in the patient's hand, despite conscious attempts not to take hold of the object in this way. There may also be changes in gait (rather similar to those seen with damage to the cerebellum), so that the patient shows *marche a petit pas*, walking rather clumsily in little rapid steps.

The tertiary level of motor control is in the next region of the frontal lobes, the prefrontal cortex, which is discussed below, but there are some specific functions associated with the three levels of the motor cortex that should be mentioned here. These concern control of the face, and the data come from the study of patients who have had the motor and sensory cortex for the *face region* on one side of the head surgically removed (Taylor, 1979). These patients do not in fact suffer a lasting problem in controlling the face, or in receiving and interpreting sensation from it, largely because the motor and sensory connections to the head (via the cranial nerves) are bilateral, and are not contralaterally organized as in the rest of the body (via the spine). On recovery, the patient's face is normally expressive, and facial movements can be imitated on command. There are some expressive speech difficulties immediately following the operation but, apart from some slight residual difficulty, this clears within the first year after surgery. The patients, rather surprisingly, nevertheless show marked difficulties with verbal fluency, phonetic discrimination, spelling (especially after a left-sided operation), and design fluency (after a right-sided operation).

The verbal fluency deficit is seen when the patient is asked to give a series of words beginning with a particular letter, or belonging to a particular category such as "fruit and vegetables," within a given time limit, usually 1 minute. (This deficit is also seen with prefrontal lesions, but is reported to be less severe.) Design fluency is tested similarly, except that here the patient is asked to make as many nonrepresentational drawings as possible within a 5-minute period. While normal subjects may produce about 15 words beginning with, say, *s* in 1 minute, patients with a verbal fluency deficit may only manage 4 or 5. They also cannot identify, with normal accuracy, phonemes (the building blocks of spoken language, roughly equivalent to syllables) that have been embedded in nonsense words, and there is an associated impairment in spelling. These difficulties occur in the absence of any other significant problems with the expression or understanding of language, and it is presumed that there is some essential connection with the motor control of the face, or alternatively in inhibiting recently produced responses, although the real origin of these deficits remains something of a mystery.

THE PREFRONTAL CORTEX

A number of rather different functions are associated with the prefrontal cortex, and this is not surprising in view of its extensive area. Prominent among these functions are several linked with motor control, which form the tertiary level of the motor control system.

The *tertiary level of motor control* exerts its influence by operating upon all lower levels of the motor system, both in the cortex and at subcortical levels. The control is therefore not of specific components of movement, but rather of the planning and programming of motor acts and their flexible adaptation to particular circumstances. Monitoring of movement patterns ensures that behavior is appropriate and adaptive, and lesions of the prefrontal cortex therefore result in motor behavior becoming inflexible and stereotyped.

An example of this inflexibility can be seen in the Wisconsin Card Sorting Test. A set of four cards is placed before the patient, as shown in (a) at the top of Figure 3.3. The cards contain one, two, three, or four shapes, each in one of four forms and in one of four colors. The patient is then asked to sort cards containing similar stimuli (b) into piles below the initial set, but without being told the rule for sorting. The cards might thus be sorted according to the number of shapes, the type of form, or the color. The examiner tells the patient whether she or he is correct after each card is sorted, so that the patient has to discover the correct rule by which to sort the cards. Normal subjects, and also

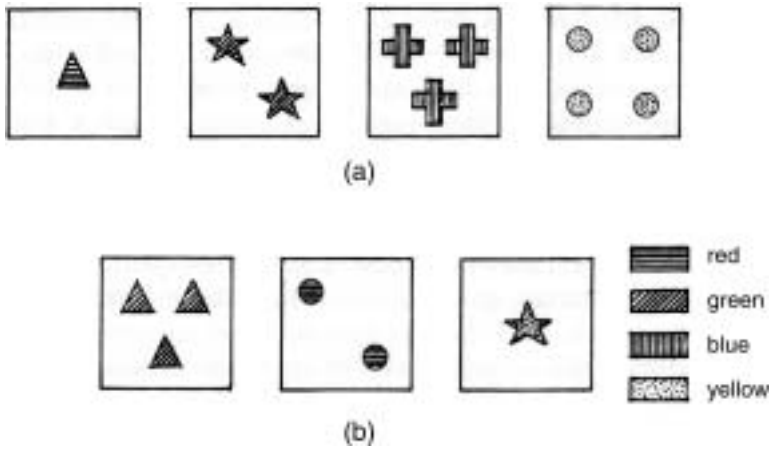

FIGURE 3.3. Wisconsin Card Sorting Test: (a) the four cards under which the test cards must be sorted and (b) examples of the test cards.

patients with frontal injuries, are able to discover this initial rule. However, after the sorting rule has been learned, the examiner changes the rule without warning the patient. This initially causes puzzlement and frustration in most subjects, but normal subjects and patients with nonfrontal lesions rapidly realize what has happened and search out the new rule; they readily adapt to subsequent changes of rule. However, frontal lobe patients are extremely slow to adapt to the new rule, and many do not manage it at all. They simply continue sorting according to the first rule, getting responses correct only by chance. This behavior, continuing with a response once it is no longer appropriate, is known as *perseveration*. The general problem seems to be one of impaired inhibition of cognitive responses; that is, once certain responses have been brought to the fore they cannot be replaced by more appropriate responses. A similar example of perseveration is seen in the patient who, asked to subtract 7 serially from 100, responds with "93 . . . 86 . . . 76 . . . 66 . . . 56 . . . " instead of "93 . . . 86 . . . 79 . . . 72 . . . "

A final example may be shown with the Stroop phenomenon. Here, subjects are asked to follow a list of words that are the names of colors but that are printed in ink of a contrasting color, and to name the color of the ink. Normal subjects take longer to go down such a list than a list of comparable words that are not color names, because the color names interfere with naming the ink colors. The interference is quite extreme in some frontal lobe patients, who find it impossible to inhibit reading the color names (Perret, 1974). The failure to inhibit associated but incorrect responses may also be seen in the responses to vocabulary tests, where the patient's response is confused with that appropriate to a similar-sounding word. For example, the patient correctly reads *river*. The next word is *see* but the patient reads it as *ocean*, confusing it with the similar sounding word *sea*.

Another aspect of motor control in prefrontal cortex is the *programming and planning* of sequences of behavior. At the level of programming simple sequences, it is best demonstrated by the 1979 work of Kolb and Milner, as cited in Kolb and Whishaw (2003). They asked patients to imitate certain facial gestures (see Figure 3.4), and found that patients with prefrontal lesions were not impaired when imitating single gestures, but when asked to copy a series of three gestures, they showed significant impairment. A similar difficulty with planning is sometimes shown by patients who perform badly on paper and pencil mazes, such as the Porteus mazes (see Figure 3.5), because they are not able to build up a sequence of moves that will get them to the goal.

Patients with difficulties of this kind may also have difficulties with *problem solving* of a more general kind, including visuo-constructive problems. When asked to perform the block design task mentioned

FIGURE 3.4. Examples of the stimuli used by Kolb and Milner, showing gestures to be copied by the patients.

above, these patients may fail. Part of the difficulty may lie in the way in which the design to be reproduced is presented, for it does not clearly show how individual blocks will form parts of the design (see Figure 3.6). If this information is given to the patient he or she may be able to perform normally. The patient's difficulty again seems to be in building up a plan of component moves to attain a complex goal. In a similar way, patients may be unable to reproduce a complex nonfigurative drawing unless they are specifically taught to build it up in a series of discrete steps.

While patients with prefrontal lesions do not show difficulty with arithmetical computations (compare the effects of parietal lesions,

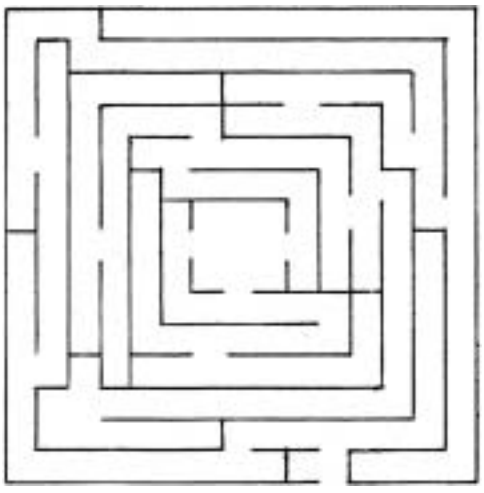

FIGURE 3.5. A maze similar to the Porteus mazes at the adult level of difficulty.

p. 108), they may have difficulty with arithmetical problems, especially if these are couched in the form of sentences, such as "There were 18 books on two shelves, and there were twice as many books on one as on the other. How many books were on each shelf?" The patient seems unable to abstract the elements of the problem, and then to arrange these into a plan for its solution (Christensen, 1975).

A final, and specialized, aspect of motor control is that *of voluntary eye movements*. Prefrontal cortex contains an area known as the *frontal eye fields*, in which eye movements related to scanning of the environment and the inspection of visual objects are controlled. This can be illustrated by comparing the recordings of eye movements of patients with damage to this area with those of normal subjects when shown a complex picture (see Figure 3.7). Normal subjects rapidly detect the picture's most significant and informative elements and follow a series of glance paths between these elements when asked to extract meaning from it. In marked contrast, those with frontal lobe injuries show a disorganized series of movements that lack the adaptive articulation of normal subjects (Yarbus, 1967). This difficulty may underlie a number of more general problem-solving deficits in frontal lobe patients, as well as the poor performance in visual search tasks (locating a target item in a larger array of similar items) that is sometimes apparent. Alternatively, all these difficulties, including the eye movement problem, may be manifestations of a basic deficit in generating and operating strategies for collecting and processing information needed for intellectual tasks.

The motor difficulties of damaged frontal lobe patients may also show in reduced spontaneous behavior, and they may therefore be

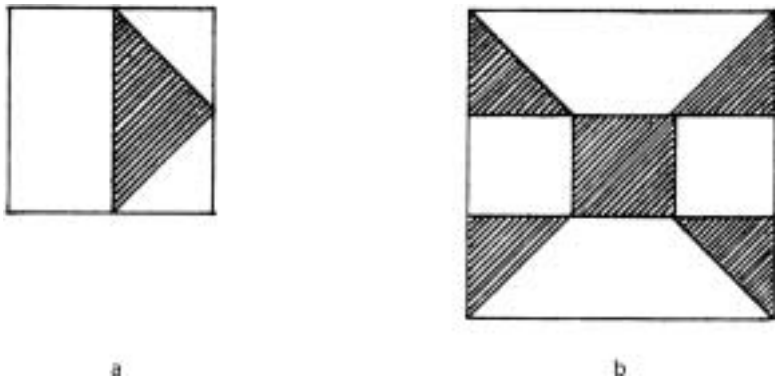

FIGURE 3.6. The type of pattern to be constructed in a block design task using four blocks (a) and nine blocks (b).

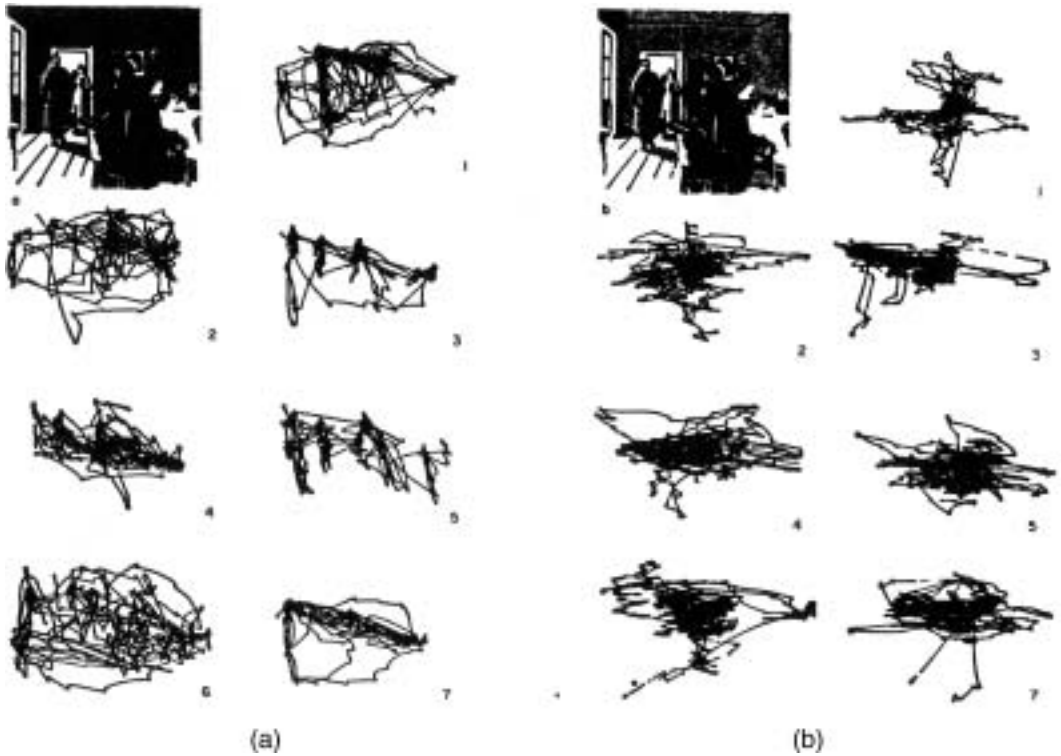

FIGURE 3.7. Eye movement patterns of (a) a normal subject and (b) a patient with a massive frontal lobe lesion while examining the picture shown top left: (1) free observation, and after the questions; (2) "Is the family rich or poor?"; (3) "How old are the people in the picture?"; (4) "What were they doing before the man entered the room?"; (5) "Can you recall how the people were dressed?"; (6) "How were the people and furniture placed in the room?"; (7) "How long had the man been away from his family?" (Reprinted from A. R. Luria, *The Working Brain*, Penguin, 1973.)

referred to as *pseudo-depressed*. Such patients sit around, have almost nothing to say, engage in little activity, and typically present a flat, emotionless expression. The deficit in verbal fluency (by which patients with frontal lesions are unable to generate a normal number of different words beginning with a given letter in a set period of time) is considered to be associated with the overall reduction in response emission (Milner, 1964). Some writers, notably Luria (Luria, Pribram, & Homskaya, 1964), have considered this and other frontal lobe motor deficits to be due to a failure in the verbal regulation of behavior.

The idea that underlies this concept *of verbal regulation* is that we use covert language to control complex motor activity. For example, you may be aware when learning some new motor skill, say driving a car, of "talking to yourself" to help sort out what to do, but with practice the skill becomes more automatic and the internal commentary is no longer necessary. It has certainly been shown by Luria that children can be helped to perform such tasks as a go/no-go problem (squeeze the bulb if the green light comes on, but do not squeeze if the red light comes on) at a younger age than would normally be possible if they are taught to use explicit verbal mediation (saying "press" or "don't press" to the green or red light). The idea is that as a skill becomes practiced, the verbal mediation becomes covert and internalized, and the difficulties that frontal lobe patients have in motor control can thus be explained in terms of a deficit in the verbal regulation of behavior. While this hypothesis is widely quoted, Drewe (1975) tested frontal lobe patients with go/no-go learning tasks and failed to find clear support for it.

Some *perceptual deficits* are also associated with prefrontal cortex. One of these is perhaps unexpected and concerns making judgments about egocentric space. Semmes and colleagues showed patients diagrams of the human figure from the front and back with numbers indicating parts of the body: the palm of the left hand, the back of the right calf, and so on. The patients were given a number and asked to point to the appropriate part of their own bodies. Frontal lobe patients did poorly on this task in comparison with patients with other lesions (Semmes, Weinstein, Ghent, & Teuber, 1963). (If you think this is an easy task, try standing in front of a mirror with a child and asking the child to point to various parts of the body while looking in the mirror.)

Associated with this deficit is impaired performance in the Aubert task. In this task the patient is seated in a dark room in a chair that can be tilted to the left or right. In front he sees a luminous rod that is to be set to the vertical. Normal subjects show an effect of head and body tilt, so that the rod is misaligned away from the horizontal in the opposite direction to that of the subject's tilt. Greater tilt produces greater error. The effect is much more pronounced in those with frontal lesions

(Teuber & Mishkin, 1954). Teuber (1964) has proposed that both of these perceptual deficits may be explained by impaired *corollary discharge*. Here, the idea is that when movements are executed, information is sent out to other parts of the system so that the effects of the movement can be anticipated and accounted for. The obvious example is that when you move your eyes the world does not appear to move but remains apparently stable. If your eyes are passively moved (try gently pushing your half-open eye with a finger on the eyelid) then the world does apparently move about. When you make active eye movements, the systems interpreting information from the eye are forewarned and make all the necessary adjustments, but these cannot be made when unexpected passive movements are imposed upon the eye. A gymnast performing on parallel bars would come dramatically unstuck if the world did not appear to remain stable as the body moved through the exercises. The perceptual world is in fact whirling about, but knowledge of the muscle movements allows all the necessary compensation to be introduced.

In the Aubert task, it is assumed that damaged frontal lobe patients fail to generate appropriate corollary discharges for the compensation in muscular tonus that occurs during tilt, leading to a faulty perception of where the vertical should be. By extension, this can be applied to the judgment of egocentric space. The patient fails to keep proper track of where his or her body is in space, and cannot accurately relate the external world to it.

One specific aspect of *memory* that is affected by prefrontal lesions is that of recency. In other words, if a patient is shown a series of items one at a time, and then shown two items, he or she may be able to recognize them correctly as having been in the list but may not be able to report correctly which of the items was presented more recently (Milner, 1971). This seems to be the only pure memory function to be affected by frontal lesions, although various aspects of learning may be affected in a secondary way by other frontal lobe deficits. In particular, *working memory* deficits, which reflect aspects of attention and concentration, may be associated with frontal lobe lesions. It is not uncommon to see patients who complain of memory problems and yet score at their premorbid level on formal tests of memory in the consulting room. The explanation is normally that in everyday life, unlike the consulting room, the patient fails to attend adequately to information so that the memories are not efficiently laid down. The memory processes function normally, but material does not get fed into these processes in a normal fashion, resulting in the problems that the patient experiences.

Owen, Evans, and Petrides (1996) proposed a two-stage model of working memory that involves, first, organization and sequencing, and

second, monitoring and manipulation. They linked the first stage to the ventrolateral frontal cortex, and the second to dorsolateral prefrontal cortex. Goldman-Rakic (1996) has proposed the concept of On-Line Memory, associated with dorsolateral prefrontal cortex, which confers the ability to hold separate pieces of information together and so blend otherwise unrelated memories into distinct lines of thought. This is a variant of the concept of working memory but with the distinct property of facilitating the association of otherwise unrelated thoughts and memories. It is attractive in explaining a range of the problems experienced by patients with frontal lobe disorders.

Deficits in attention feature in a number of models of frontal lobe function. Attention is a complex concept, but an influential contemporary model has been provided by Posner and Petersen (1990), although it is not without its critics. According to this model there are three main components in the attentional process: disengaging the current focus of attention (detection, a function of the posterior parietal cortex); shifting attention to a new location (orientation—frontal eye fields and related structures); reengagement at the new location (discrimination—thalamus). However, also involved in the two latter processes is the cingulate gyrus. The cingulate gyrus is on the medial surface of the frontal lobes, tucked into the midline division between the two hemispheres. In light of its protected position, it is rarely directly damaged in cerebral trauma, and therefore not well understood, but may well nonetheless be involved in the attentional deficits that then have a consequential impact upon other frontal lobe functions.

BROCA'S AREA

The third region of the frontal lobes is Broca's area, which is sited in the left frontal lobe and has the primary function of expressive speech. This, however, will be discussed with other elements of the language system in Chapter 7.

THE ORBITAL CORTEX

The final region of the frontal lobes subserves aspects *of personality* and *social behavior.* The classic example of the effects of lesions of this area is that of Phineas Gage, a construction worker on the American railroads who in 1848 suffered an accident in which an iron bar, over 3½ feet long and 1¼ inches thick, was blown through the front of his head, entering at the lower cheek and exiting from the upper forehead (see Fig-

FIGURE 3.8. The skull of Phineas Gage, after a contemporary drawing.

ure 3.8). Gage survived but underwent a marked change in personality. From being a capable foreman and an efficient worker (Harlow, who attended Gage and reported the case, says he was "energetic and persistent in executing all his plans of operation"), he became impulsive, willful, inconsiderate, and obstinate. He took to swearing, which had not previously been his habit, and continually changed his mind. Indeed, he was so dramatically altered that his "friends and acquaintances said that he was no longer Gage."

Although this type of personality change generally follows only large, and usually bilateral, frontal injuries (often the result of road traffic accidents), it is not at all uncommon. The changes may also be accompanied by what can only be described as silliness, and patients may constantly sing, whistle, and repeat rather poor jokes. In fact there is a term for this puerile kind of jocularity: *witzelsucht*. An additional symptom may be a lack of the social graces; these patients engage quite freely in belching, picking their noses, and even less savory socially proscribed activities in public, without any apparent concern. A similar effect can sometimes be seen in the maze performance of frontal lobe patients. They may simply go through the walls of the maze, failing to pay attention to the rules governing performance. Alternatively, asked to learn a maze pathway in which the correct path is not apparent (e.g., the stylus maze; Milner, 1965) but in which feedback is given at each point, the patients do badly because they fail to obey the rules or make appropriate use of the feedback information given to them. An alternative pattern of response may be that of indifference, lack of initiative, and general loss of drive, part of the pseudo-depression already noted. These

patients say very little and exhibit almost no emotional expression. This may also be partly associated with *anhedonia*, a loss of the ability to experience pleasure.

Finally there may be associated changes in *sexual behavior.* These may be in terms of a loss of social inhibitions, resulting in exhibitionism and public masturbation, although the amount of sexual activity is not increased. However, the changes are more often in terms of a loss of libido (which may also be associated with prefrontal lesions). The capacity for sexual activity is not lost, but patients lose interest in it.

Orbital lesions may therefore result in personality and social behavior changes that may loosely be characterized by impulsiveness, facetiousness, and mild euphoria; by diminished anxiety and concern for the future; and by lack of initiative and spontaneity. It was these observations that led to this area being the site of the prefrontal leucotomy, which will be discussed in Chapter 9.

Substantial injuries to the frontal lobe, particularly where there is both a change in personality and difficulties of planning and execution, can be among the most disabling of cerebral injuries. For obvious reasons, road traffic accidents not infrequently result in extensive frontal damage. It is common to see patients who, despite scoring normally on conventional tests of general cognitive ability, require 24-hour care and supervision. This is because, although their intellectual functions are retained, they are unable to apply these cognitive skills appropriately in their everyday life. Such patients may compromise their own safety by leaving the stove lit, the gas turned on, or taps running, or failing to lock doors. They are vulnerable to the persuasions of salesmen at their door and make ill-considered financial decisions; they are generally unable to budget their own money. They fail to plan meals or to shop and stock their larder sensibly, and may also neglect their own hygiene and fail to change or wash their clothes. Activities are impulsively conceived but rarely carried out, or if begun not completed. Domestic bills go unpaid.

In some of these individuals, particularly if there is some preaccident history of aggressive behavior, there may be poor temper control and episodic aggression. Although there is usually some trigger for this aggressive behavior in the form of frustration or irritation, the response is disproportionate and poorly controlled and it can result in significant violence. Young men with this problem (and they are those most likely to be involved in road traffic accidents) can frequently end in trouble with the police as a result of their neurological injury. There are drugs that can assist with this problem, but the lack of insight that often accompanies the disorder makes behavioral change difficult to achieve.

In general, this *frontal lobe syndrome* is difficult to rehabilitate because of the lack of insight and awareness on the part of patients. If

frontal lobe patients were aware of their problem, they would no longer have the problem, retaining the cognitive abilities to perform the relevant tasks appropriately. It is this lack of insight, and the inability to weigh matters in the balance and appreciate the consequences of their actions, that makes the frontal lobe syndrome so disabling and leads to a substantial, and lifelong, need for care and supervision.

An interesting aspect of the frontal lobe syndrome is that it can be difficult to demonstrate and assess in the consulting room. In an environment where there are clear task demands and few distractions, these patients can perform cognitive tasks surprisingly well. Most psychological tests involve clear instructions and a procedure that is controlled by the examiner, and as a result the examiner "acts as the patient's frontal lobes." A number of tests have been devised that attempt to bring a more naturalistic element into the examination, most notably the Behavioural Assessment of the Dysexecutive Syndrome (BADS; Wilson, Alderman, Burgess, Emslie, & Evans, 1996). There are a number of tests in this battery, but most require some planning and organization on the part of the patient. For example, in Key Search patients must draw a route on the plan of a field to show how they would search the field to be sure to find keys they had lost somewhere in the field. In the Zoo Maps a visit to the zoo must be planned with the locations to be visited listed and a number of rules provided governing the route to be taken. Again, subjects draw their planned route once they have worked out what it should be.

In another test, the Cognitive Estimates Test (CET; Shallice & Evans, 1978), patients must estimate quantities, which they are unlikely to know, by reasoning from their real world experience. Typical questions are "At what speed do racehorses gallop?" and (my favorite question), "How many camels are there in Holland." Minor inaccuracies are allowed; it is the extreme and "bizarre" estimates that are of clinical significance—the patient who considers that racehorses gallop at either 10 or 80 miles per hour. Such tasks are helpful in identifying frontal lobe problems, but the correspondence between poor test scores and problems in everyday life remains rather weak.

MODERN THEORIES OF FRONTAL LOBE FUNCTION

One difficulty, which will be apparent from the preceding discussion, is that there is a broad variety of behaviors associated with the functions of the frontal lobes. Rather than seeking an overall encompassing explanation of frontal lobe function, modern theories have rather concentrated on how diverse processes might be integrated.

The most influential of these theories has been Shallice's Supervisory Attentional System (SAS) model (Shallice, 1982, 2002; Shallice & Burgess, 1996). The basic model is illustrated in Figure 3.9.

The essential idea is that there are schema control units (a schema refers to a plan of action) that govern patterns of action, operating on the basis of information received from the perceptual system. There are inhibitory links among the schema control units that permit the most important activity to be dominant. The way they operate, and so govern the pattern of behavior, is controlled by a "contention scheduling system," which ensures that appropriate priority for behaviors is maintained. When a novel goal state arises (the individual needs to perform a novel behavior) then this nonroutine activity requires the intervention of the overarching supervisory attentional system. The model has at least two major advantages in that it explains distractibility, as strong cues cannot be overridden by the SAS, and it also explains perseveration by the dominance of particular schemas that the SAS is unable to displace. In subsequent versions the model has become very much more complex, incorporating attentional systems, among others. Nevertheless, it provides a useful framework for demonstrating how particular behaviors may be triggered by particular stimuli, and how automatic behaviors

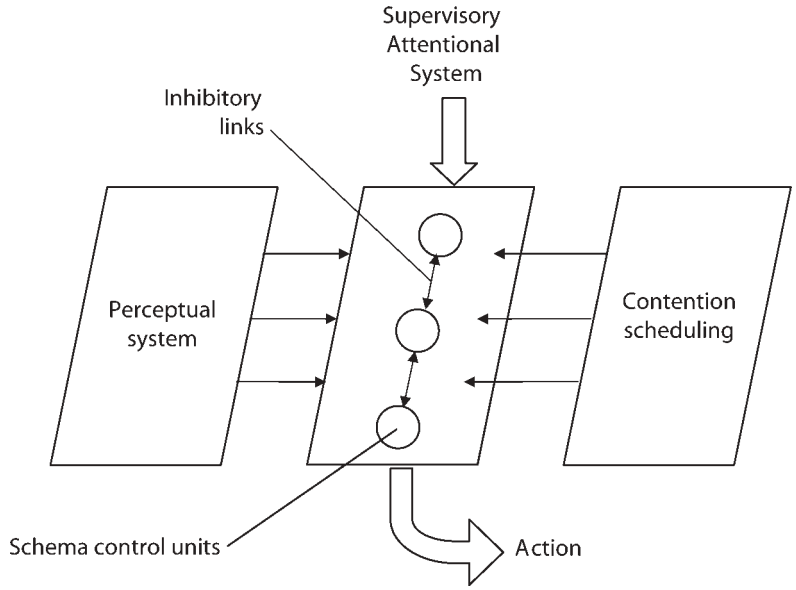

FIGURE 3.9. Shallice's model of the Supervisory Attentional System. (Redrawn after Shallice, 1982.)

may be initiated and terminated. It is less adequate in describing how new behaviors are formulated and selected in the prefrontal cortex.

Another influential model has been that of Stuss and Benson (Stuss & Benson, 1986; Stuss & Knight, 2002). In its fundamentals, this model sees the frontal cortex as involved in a series of processes controlling behaviors. In the first stage, *drive* and motivation are modulated by the orbital region, while medial structures are linked to the initiation of activity. Secondly, *sequencing* in both dorsolateral prefrontal cortex and orbital cortex creates and maintains temporal order. The third and fourth processes *anticipate* and *select* salient goals, to be followed by procedures for *preplanning* the behaviors required for potential outcomes. Finally, *monitoring* evaluates the success of these outcomes.

An alternative approach has been to recognize the relevance of emotion in behavioral control. Failures of emotional perception have now been recognized as associated with both the orbital and cingulate cortices. This deficit as now sometimes termed *alexithymia*, literally an inability to read emotions. Perceptual disorders of emotional recognition may relate to acknowledging one's own emotional state, but may also be expressed in a deficit of identifying emotions in the faces or voices of others. There are two important models broadly associated with this observation, associated with Rolls and with Damasio.

Rolls (2000) argued that the orbital cortex is deeply involved in the processing of both taste and olfaction, but that it also establishes the reward value for secondary reinforcers. Hence, this region of the frontal lobe provides a means of establishing secondary reinforcers on the basis of more primitive responses and providing a reward value for a variety of other environmental stimuli. This concept is a development, albeit a more detailed and sophisticated one, of the observation already noted, that frontal lobe patients may experience anhedonia and so fail to experience appropriate rewards as a consequence of their behavior; as a result the behaviors decline in frequency and such patients become relatively apathetic and inert. (Those interested in a brief but authoritative review of the brain systems underlying emotion should consult Dalgleish, 2004.)

Damasio's Somatic Marker Hypothesis (Damasio, 1997, but a popular and readable account is to be found in Damasio, 2006) recognizes that the brain cannot be considered to be independent of the body in which it is placed, the somatic environment. Specific stimuli trigger the reactivation of somatosensory patterns that act as markers of these stimuli. The reactivation may occur through neural interactions with the body ("body loops") or simply within the somatosensory maps of the cortex. The reactivation constrains reasoning and decision making as the somatic marker provides a biasing system, outside consciousness, that

facilitates either appetitive or avoidance behavior. As situations with personal or social significance are generally associated with reward and punishment, with pleasure and with pain, these somatic markers provide critical signals in many situations of reasoning and decision making, especially if some social context is involved. While Damasio's model does not permit the detailed predictions concerning cognitive behavior that are afforded by other models, it provides a salutary lesson in the poverty of considering the brain apart from its biological environment.

LATERALIZATION OF THE FRONTAL LOBE

A theme that runs through almost all of this book is that of cerebral lateralization. It has been clear throughout the history of neuropsychology that there are differences between the functional specializations of the two hemispheres. In terms of clinical evidence, this means that some deficits are more frequently associated with right sided lesions and some with left, and some deficits only appear with bilateral lesions (in both hemispheres). It should be emphasized that this is rarely a firm distinction, but is one *of relative specialization*. The evidence relating to frontal lobe injuries makes this clear.

Benton (1968) constructed a study in which he gave six tests to a group of patients with either left, right, or bilateral frontal lobe damage. Two of the tests (Verbal Fluency and Verbal Learning) were expected to be associated with left sided lesions, and indeed in both tests the patients with left lesions more frequently showed a deficit than those with right lesions. Those with bilateral lesions had difficulty as frequently as those with left lesions for Verbal Fluency, and more often for Verbal Learning. The "right hemisphere tasks" (Block Design and Design Copying) also produced the expected results: those with right lesions or bilateral lesions had a deficit more commonly than those with left lesions. The final two tests (Time Orientation—to see if patients know the time, day, and date and can locate themselves in time—and the Gorham Proverbs Test, in which the patient must explain the meaning of some well-known proverbs) showed that impaired performance was associated much more frequently with bilateral lesions than with unilateral lesions of either side.

These hemisphere specializations can loosely be divided into verbal and symbolic (left hemisphere) versus visuospatial (right hemisphere), although we shall question the validity of this distinction in Part III. In fact, evidence against such a simple dichotomy is already apparent in that failure in the Proverbs task only occurs commonly with bilateral lesions. Also, the test of identification of body parts in egocentric space

that has already been mentioned is associated with lesions of the left frontal lobe, and not the right, as might have been expected. This information on lateralization is important, not only because it helps in locating lesions in patients under examination, but also for the construction of neuropsychological models of the organization of the brain.

CONCLUSION

Some of the most important specific functions associated with the frontal lobes have been discussed, and are summarized in Table 3.2.

Although we have no space to deal with it here, there is very considerable research literature on the effects of frontal lobe lesions in animals. The evidence that this provides is extensive and complex, but given the difficulties of generalizing results even from apes to humans, the results are remarkably similar. Some deficits found in higher animals do not have clear parallels in humans, but there are few fundamental disagreements. (See the Further Reading section at the end of this chapter for the various reviews that are available.) With reference to the suggestion that the frontal lobes are in some way special in man, neither the evidence

TABLE 3.2. Some Specific Functions Associated with Regions of the Frontal Lobe

Motor and premotor cortex:
Primary and secondary levels of motor control
Verbal fluency and design fluency
Spelling
Prefrontal:
Tertiary level of motor control
Adaptability of response pattern
Programming and planning of sequences of behavior
Level of response emission
Verbal regulation
Problem solving
Voluntary eye movements
Perceptual judgment
Memory and attention
Broca's area:
Expressive speech
Orbital cortex:
Personality
Social behavior

from animal studies (when compared with human clinical data) nor that from patients with brain damage would support this conclusion. We may still regard the frontal lobes as undertaking some of the highest intellectual tasks in humans, but there is no essential discontinuity between these abilities in humankind and those in the higher animals.

Is it possible to conceive of general neuropsychological systems that might account for the deficits found in the frontal lobes? Despite recent advances, the answer at present is no, which should hardly surprise us in view of the extent of frontal cortical tissue. Teuber's corollary discharge theory holds some, but not complete, explanatory power. Luria (1973) has suggested that the three special functions of the frontal lobes are the regulation of activation processes; the execution of verbally programmed behavior processes; and problem-solving behavior. This explanation is also incomplete, and cannot be supported in all its details by scientific evidence. A general theory that the frontal lobes operate by undertaking the temporal structuring of behavior (Fuster, 1980) is no more satisfactory. The more recent theories of Shallice and Burgess, Stuss, Rolls, and Damasio discussed above have all provided useful insights and new ways of conceptualizing the contribution of the frontal lobes, but have yet to succeed in providing a single integrated model of frontal functions. The frontal lobes are involved in many functions, and we are not yet at the stage where neuropsychological systems can be so explicitly summarized. Nor are many neuropsychologists sure whether they are seeking a single theory of frontal lobe function, or whether the ideal model would relate general functions to more circumscribed areas within the frontal lobes. The delineation of the frontal lobes is, in any event, a rather artificial construct (as for all the lobes) and it may be entirely unreasonable to maintain the ambition of a simple description of their functions.

We can conclude that the frontal lobes play a major role in the higher levels of motor control and in the planning and controlled execution of motor acts and skills. They contribute also to general problem-solving behavior, and the regulation of eye movements is an important aspect of this performance. Associated with these functions, in prefrontal cortex, are some specific verbal abilities, some perceptual functions, and some limited aspects of memory. Frontal regions are also involved in the regulation of attention, and in motivation and the regulation of behavior more generally. Lesions, especially in the orbital cortex, may lead to changes in personality and social behavior.

At about the turn of the 20th century, Hughlings Jackson described the frontal lobes as the "least organized" area of the cortex. It has always also been the least understood, and remains the most challenging to neuropsychologists.

FURTHER READING

There are some general texts that apply to all the chapters in Part II, and these have already been listed at the end of Chapter 1 (p. 20). Some texts that relate more specifically to the frontal lobes will be found among the references below.

REFERENCES

Benton, A. L. Differential Effects of Frontal Lobe Disease, *Neuropsychologia*, 6 (1968), 53–60.

Black, F. W. Cognitive Deficits in Patients with Unilateral War-Related Frontal Lobe Lesions, *Journal of Clinical Psychology*, 32 (1976), 366–372.

Christensen, A.-L. *Luria's Neuropsychological Investigation* (Copenhagen, Denmark: Munksgaard, 1975).

Dalgleish, T. The Emotional Brain, *Nature Reviews: Neuroscience*, 5 (2004), 582–589.

Damasio, A. R. Towards a Neuropathology of Emotion and Mood, *Nature*, 386 (1997), 769–770.

Damasio, A. *Descartes' Error: Emotion, Reason, and the Human Brain* (Revised edition, New York: Vintage Books, 2006).

Drewe, E. A., No-No Go Learning After Frontal Lobe Lesions in Humans, *Cortex*, 11 (1975), 8–16.

Duncan, J. D., Seitz, R. J., Kolodny, J., Bor, D., Herzoz, H., Ahmed, A., et al. A Neural Basis for General Intelligence, *Science*, 289 (2000), 457–460.

Fuster, J. M. *The Prefrontal Cortex* (New York: Raven Press, 1980).

Goldman-Rakic, P. S. The Prefrontal Landscape: Implications of Functional Architecture for Understanding Human Mentation and the Central Executive, *Philosophical Transactions of the Royal Society B: Biological Sciences*, 251 (1996), 1443–1445.

Kolb, B., & Whishaw, I. Q. (Eds.). *Fundamentals of Human Neuropsychology* (San Francisco: Freeman, 2003).

Luria, A. R. *The Working Brain* (London: Penguin, 1973).

Luria, A. R., Pribram, K. H., & Homskaya, E. D. An Experimental Analysis of the Behavioural Disturbance Produced by a Left Frontal Arachnoidal Endothelioma (Meningioma), *Neuropsychologia*, 2 (1964), 257–280.

Milner, B. Some Effects of Frontal Lobectomy in Man, in J. M. Warren & K. Akert, eds., *The Frontal Granular Cortex and Behavior* (New York: McGraw-Hill, 1964).

Milner, B. Visually-guided Maze Learning in Man: Effects of Bilateral Hippocampal, Bilateral Frontal, and Unilateral Cerebral Lesions, *Neuropsychologia*, 3 (1965), 317–338.

Milner, B. Interhemispheric Difference in the Localization of Psychological Processes in Man, *British Medical Bulletin*, 27(1971), 272–277.

Owen, A. M., Evans, A. C., & Petrides, M. Evidence for a Two-Stage Model of Spatial Working Memory Processing with the Lateral Frontal Cortex: A Positron Emission Tomography Study' *Cerebral Cortex*, 6 (1996), 31–38.

Perret, L., The Left Frontal Lobe of Man and the Suppression of Habitual Responses in Verbal Categorical Behaviour, *Neuropsychologia*. 12 (1974), 323–330.
Posner, M. I., & Petersen, S. E. The Attention System of the Human Brain, *Annual Review of Neuroscience*, 13 (1990), 25–42.
Prochazka, A., Mushahwar, V. K., & McCreery, D. B. Neural Prostheses, *Journal of Physiology*, 533 (2001), 99–109.
Reitan, R. M., & Davison, L. A. *Clinical Neuropsychology* (New York: Wiley, 1974).
Rolls, E. T. The Orbitofrontal Cortex and Reward, *Cerebral Cortex*, 10 (2000), 284–294.
Semmes, J., Weinstein, S., Ghent, L., & Teuber, H.-L. Impaired Orientation in Personal and Extrapersonal Space, *Brain*, 86 (1963), 747–772.
Shallice, T. Specific Impairments of Planning, *Philosophical Transactions of the Royal Society B: Biological Sciences*, 298 (1982), 199–209.
Shallice, T. Fractionation of the Supervisory System, in D. T. Stuss & R. T. Knight, eds., *Principles of Frontal Lobe Functioning* (New York: Oxford University Press, 2002).
Shallice, T., & Burgess, P. W. The Domain of Supervisory Processes and the Temporal Organization of Behaviour, *Philosophical Transactions of the Royal Society B: Biological Sciences*, 351 (1996), 1405–1412.
Shallice, T., & Evans, M. E. The Involvement of the Frontal Lobes in Cognitive Estimation, *Cortex*, 14 (1978), 294–303.
Stuss, D. T., & Benson, F. D. Control of Cognition and Memory, in E. Perecman, ed., *The Frontal Lobes Revisited* (Hillsdale, NJ: Erlbaum, 1986).
Stuss, D. T., & Knight, R. T. (Eds.). *Principles of Frontal Lobe Function* (New York: Oxford University Press, 2002).
Taylor, L. Psychological Assessment of Neurological Patients, in T. Rasmussen & R. Marino, eds., *Functional Neurosurgery* (New York: Raven Press, 1979).
Teuber, H.-L. (1964). The Riddle of Frontal Lobe Function in Man, in M. Warren & K. Akert, eds., *The Frontal Granular Cortex and Behavior* (New York: McGraw-Hill, 1964).
Teuber, H.-L., & Mishkin, M. Judgment of Visual and Postural Vertical after Brain Injury, *Journal of Psychology*, 38 (1954), 161–175.
Wilson, B. A., Alderman, N., Burgess, P. W., Emslie, H., & Evans, J. J. *The Behavioural Assessment of the Dysexecutive Syndrome* (Flempton, UK: Thames Valley Test Company, 1996).
Yarbus, A. L. *Eye Movements and Vision* (New York: Plenum Press, 1967).

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