and delusional beliefs of patients with certain cognitive disorders were once dismissed as beyond understanding. Cognitive neuroscience provides us with a framework for understanding how these experiences and beliefs can arise from specific alterations in normal cognitive mechanisms.

Differences Between Conscious and Unconscious Processes in Perception Can Be Seen in Exaggerated Form After Brain Damage

The relationship between sensory stimulation and perception is far from direct. Perception can change without any change in sensory stimulation, as illustrated by ambiguous figures such as the Rubin figure and the Necker cube (Figure 59–2). Conversely, a big change in sensory stimulation can occur without the observer being aware of this change—the perception remains constant. A compelling example of this is change blindness.

To demonstrate change blindness, two versions of a complex scene are constructed. In one well-known example developed by Ron Rensink, the picture consists of a military transport plane standing on an airport runway. In one of the two versions, an engine is missing. If these two pictures are shown in alternation on a computer screen, but critically interspersed with a blank screen, it can take minutes to notice the difference even though it is immediately obvious when pointed out. (See Figure 25-8 for another example.)

In light of these phenomena, we can explore the neural activity associated with changes in perception when there is no change in sensory stimulation. Likewise, we can discover whether changes in sensory input are registered in the brain even if not represented in consciousness. We can ask whether there is some qualitative difference between the neural activity associated with conscious as opposed to unconscious processes.

Two important results have emerged from studies of the neural activity associated with specific types of conscious percepts. First, certain kinds of percepts are related to neural activity in specific areas of the brain. Those brain areas that are specialized for recognition of certain kinds of objects (eg, faces, words, landscapes) or for certain visual features (eg, color, motion) are more active when the object or the feature is consciously perceived (Figure 59–3). For example, when we perceive the faces in the Rubin figure, there is more activity in the area of the fusiform gyrus, which is specialized for the processing of faces.

This observation also applies to deviant perception (hallucinations). After degeneration of the peripheral visual system leading to blindness, some patients experience intermittent visual hallucinations (Charles Bonnet syndrome). These hallucinations vary from one patient to another: Some patients see colored patches, others see grid-like patterns, and some even see faces. Dominic ffytche found that these hallucinations are associated with increased activity in the secondary visual cortex, and the content of the hallucination is related to the specific locus of activity (Figure 59–4). Schizophrenic patients frequently experience complex auditory hallucinations, which usually have the form of voices talking to or about the patient. These

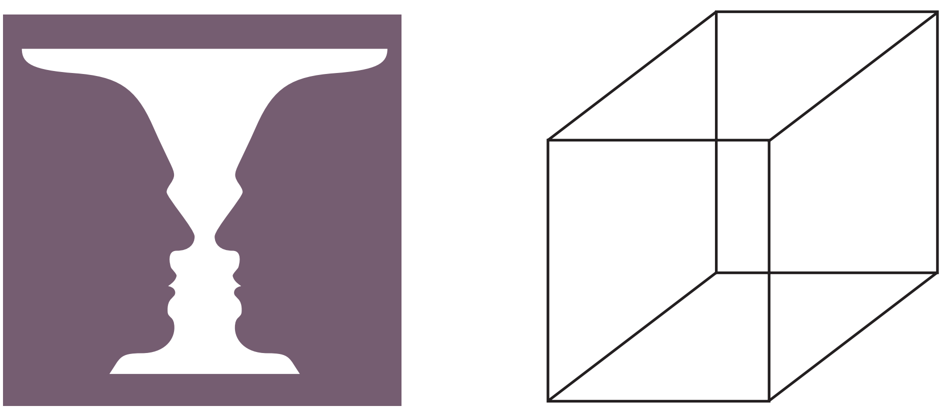

Figure 59–2 **Ambiguous figures.** If you stare at the figure on the left (the Rubin figure), you sometimes see a vase and sometimes two faces looking at each other. If you stare at the figure on the right (the Necker cube), you see a three-dimensional cube, but the front face of the cube is sometimes seen at the bottom left and sometimes at the top right. In each figure, the brain finds two equally good, but mutually exclusive, interpretations of what is there. Our conscious perception spontaneously alternates between these two interpretations.

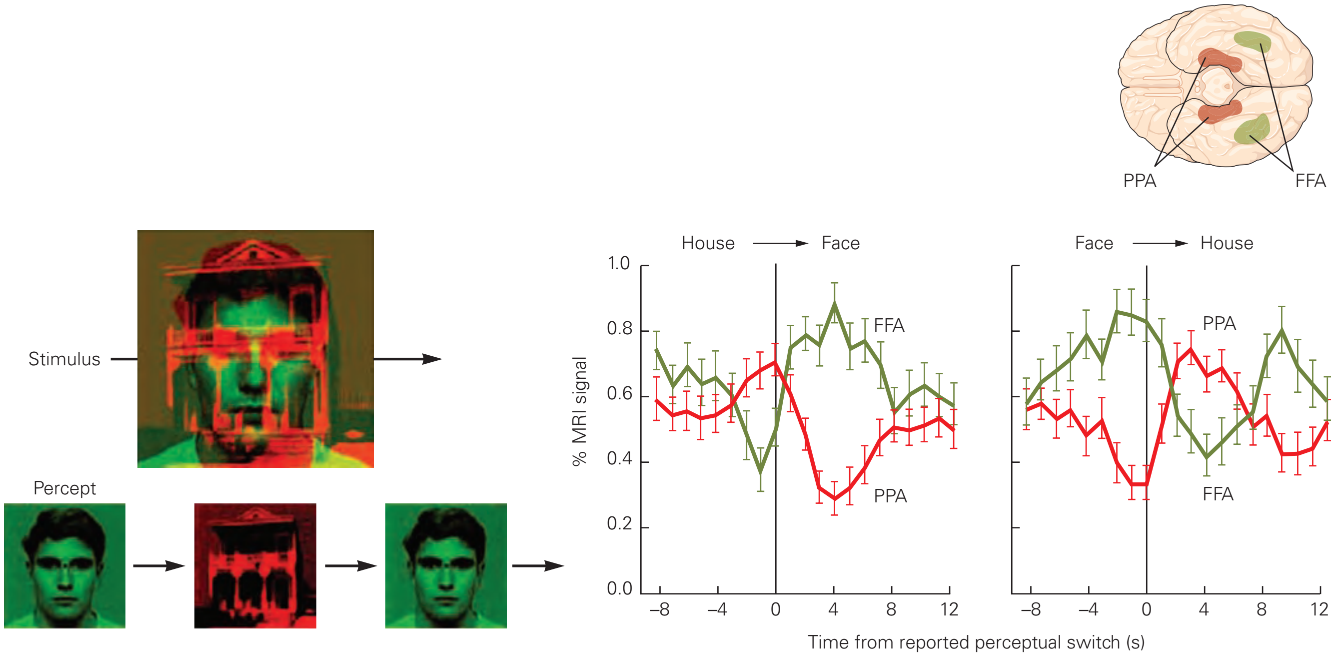

Figure 59–3 Neural activity associated with ambiguous visual information. An ambiguous stimulus was created by simultaneously presenting a face to one eye and a house to the other eye. Brain activity was measured while subjects observed these images. Subjects were instructed to press a button whenever a spontaneous switch in perception occurred (because of binocular rivalry). When the face is perceived (*left*), activity increases in the fusiform face area (**FFA**); when the house is perceived (*right*), activity increases in the parahippocampal place area (**PPA**). (Abbreviation: **MRI**, magnetic resonance imaging.) (Reproduced, with permission, from Tong et al. 1998. Copyright © 1998 by Cell Press.)

hallucinations are associated with activity in the auditory cortex.

These observations suggest that conscious experience may result from activity in certain cortical regions. This idea is difficult to test experimentally, but in the 1950s, the neurosurgeon Wilder Penfield found that electrical stimulation of the cortex in patients undergoing neurosurgery can generate a conscious experience. More recently, it has been found that transcranial magnetic stimulation of the cortex in the region of V5/MT can lead to seeing moving light flashes.

The second important conclusion drawn from studies that seek to correlate neural activity and specific percepts is that activity in a specialized area is necessary but not sufficient to yield conscious experience. For example, in the change blindness paradigm, subjects are often unaware of large changes in the picture they are viewing. If the change involves a face, activity is elicited in the fusiform gyrus whether or not the subject is aware of the change. But when the sensory change is also perceived consciously, there is, in addition, activity in the parietal and frontal cortices (Figure 59–5).

These observations are relevant to our understanding of unilateral neglect. Since objects on the left side still elicit neural activity in the visual cortex, it may be that the damage in the right parietal cortex simply prevents the formation of *conscious* representations of objects on the left side of space. Nevertheless, this sensory activity can support an unconscious inference in patients that they would not want to live in the house that is burning on the left side.

Stimuli that do not enter awareness can also elicit overt responses. A face with a fearful expression elicits a fear response in the autonomic nervous system, measured as an increase in skin conductance (galvanic response) because of sweating. This response occurs even if the face is immediately followed by another visual stimulus, such that the face is not consciously perceived. There may be an advantage to having a rapid but low-resolution system for recognizing dangerous things. We jump first; only later, on the basis of a slow, high-resolution system, are we able to identity the object that made us jump (Chapter 48). Damage in one or the other of these two recognition systems can explain certain otherwise puzzling neurological and psychiatric disorders.

Prosopagnosia is a perceptual disorder in which faces are no longer recognizable. The patient knows

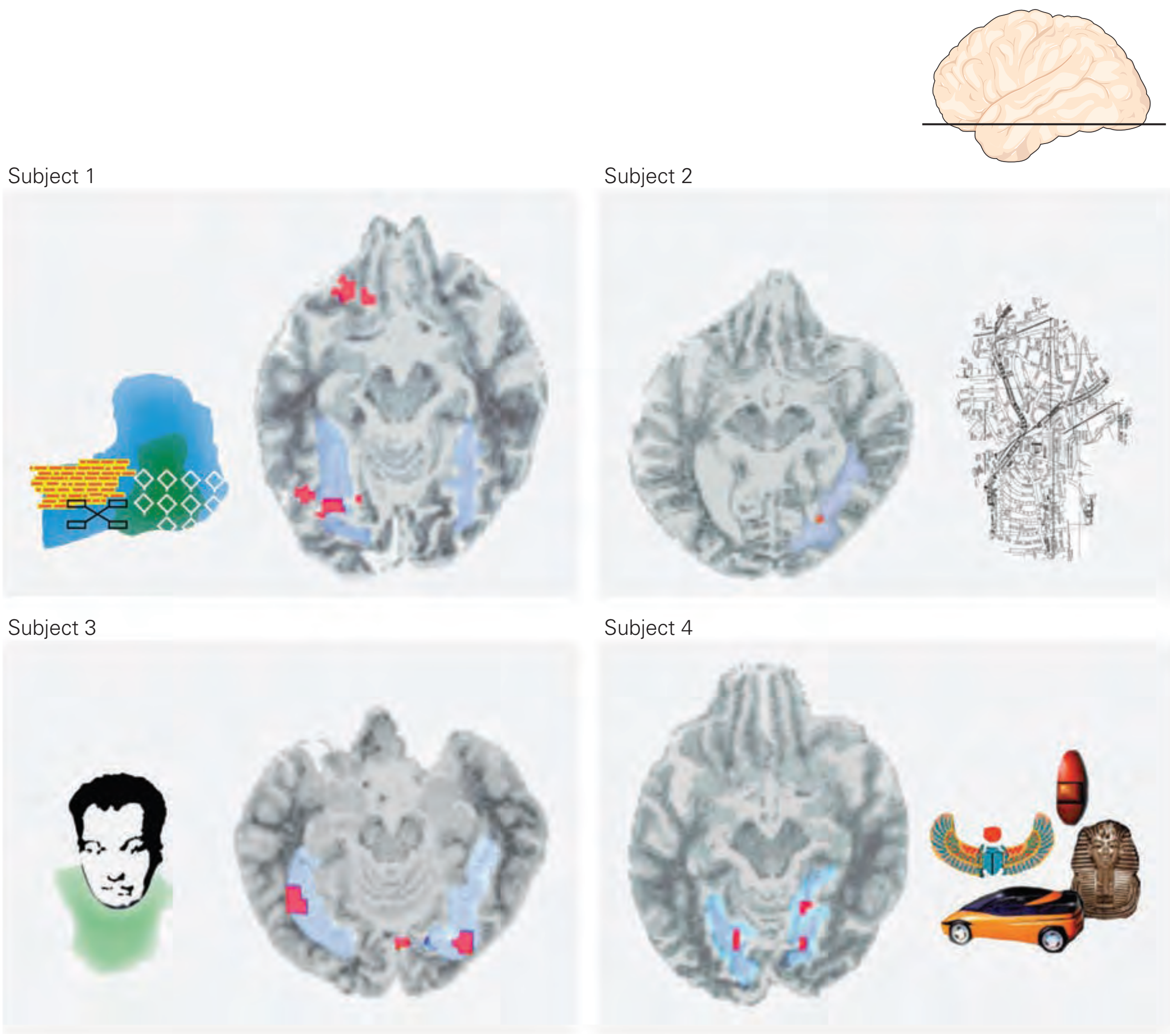

Figure 59–4 Neural activity associated with visual hallucinations. Some patients with damage to the retina experience visual hallucinations. The location of the neural activity and the content of the hallucination are related. The experience of colors, patterns, objects, or faces is associated with heightened activity (**red**) in specific regions of inferior temporal cortex. The **blue** area is the fusiform gyrus. (Reproduced, with permission, from ffytche et al. 1998. Copyright © 1998 Springer Nature.)

he is looking at a face but cannot recognize the face, even a beloved face known for years. The problem is specific to faces, since the patient may still be able to recognize the person from their clothes, gait, and voice. However, patients with prosopagnosia are able to identify faces unconsciously. They show autonomic responses to familiar faces and do better than chance when asked to guess whether or not a face shown to them belongs to a person who is familiar. In fact, their awareness of the autonomic (emotional) responses elicited by a face may enable them to judge familiarity.

Capgras syndrome, a delusion that is occasionally observed in schizophrenic patients and in some patients suffering from brain injury or dementia, produces a more unsettling experience. These patients firmly believe that someone close to them, usually a husband or wife, has been replaced by an impostor. They claim that the person, although similar if not identical in appearance, is in fact someone else. Often, this delusion is acted on with the demand that the impostor leave the house.

Hadyn Ellis and Andy Young have suggested that this bizarre delusion is the mirror phenomenon of prosopagnosia. According to this view, the circuitry for face recognition is intact, but the circuitry that mediates the emotional response to the face is not. As a result, patients recognize the person in front of them but, because the emotional response is lacking,

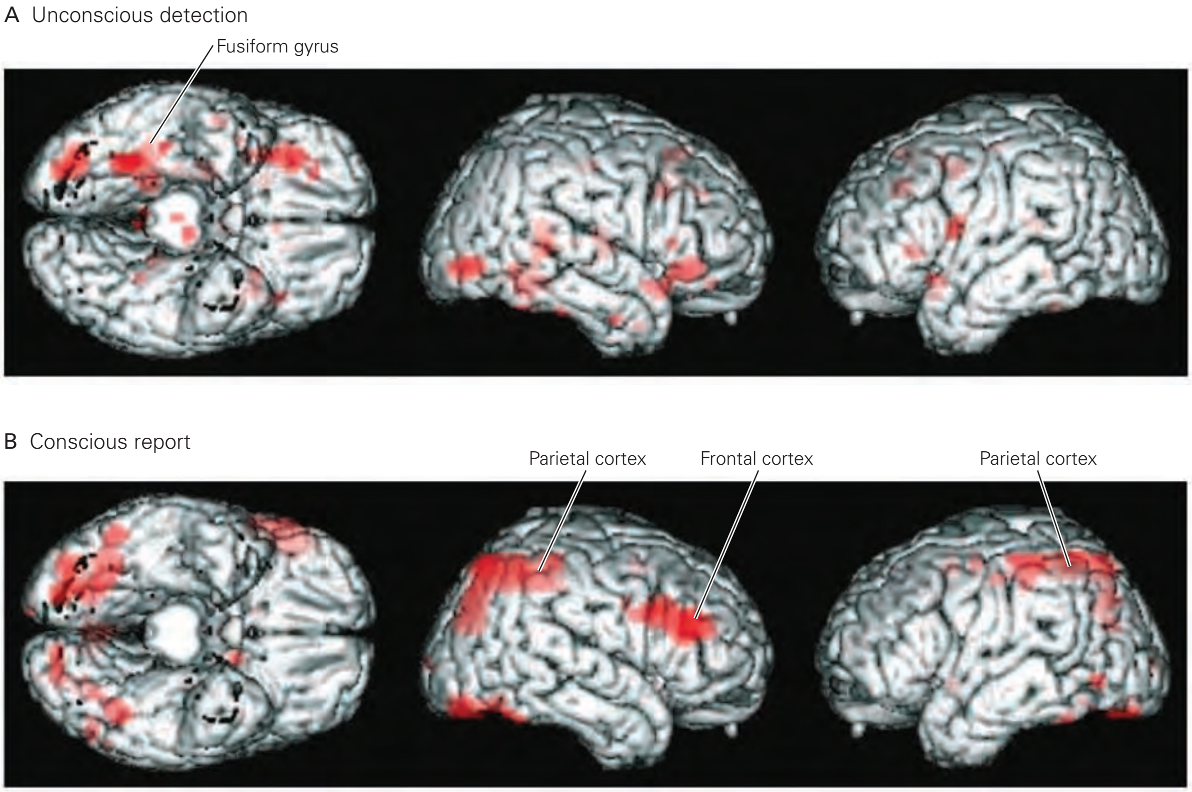

Figure 59–5 Brain activity with and without awareness. Activity in the fusiform face area increases when the face viewed by subjects changes, whether subjects are unaware of the change or conscious of it. When subjects are aware of the change, activity in parietal and frontal cortex also increases. (Reproduced, with permission, from Beck et al. 2001.)

feel that there is something fundamentally wrong. This account has been partially confirmed by the observation that these patients do not have normal autonomic responses to familiar faces.

This explanation implies that Capgras delusions are not the consequence of disordered thinking but of disordered experience. A patient sees the face of his wife without having the normal emotional response. The conclusion that this is not his wife but an impostor is a cognitive response to this abnormal experience, the mind's attempt to explain the experience.

The Control of Action Is Largely Unconscious

The sense that we are in control of our own actions is a major component of consciousness. But are we aware of all aspects of our own actions? David Milner and Mel Goodale studied a patient known as D.F. who demonstrates a striking lack of awareness of certain aspects of her own actions. As a result of damage to her inferior temporal lobe caused by carbon monoxide poisoning, D.F. suffers from *form agnosia*—she is unable to identify the shapes of things. She cannot distinguish a square from an oblong card and cannot describe the orientation of a slot. Yet when she picks up the oblong card to place it through the slot, she orients her hand and forms her grasp appropriately because of the unconscious operation of visuomotor circuits (Figure 59–6).

This sort of unconscious guidance is not unique to patients with brain damage. It is simply revealed more starkly in the case of D.F. because the system that normally brings visual information about shape into consciousness is impaired. Indeed, we can all make rapid and accurate grasping movements without being aware of the perceptual and motor information that is being used to control these movements. Sometimes, we are not even aware of having made the movement. This largely unconscious system for visually guided reaching and grasping is analogous to, and probably overlaps with, the rapid but poor-resolution system associated with fear responses.

Although we may not be aware of the perceptual and motor details of actions like reaching and grasping,

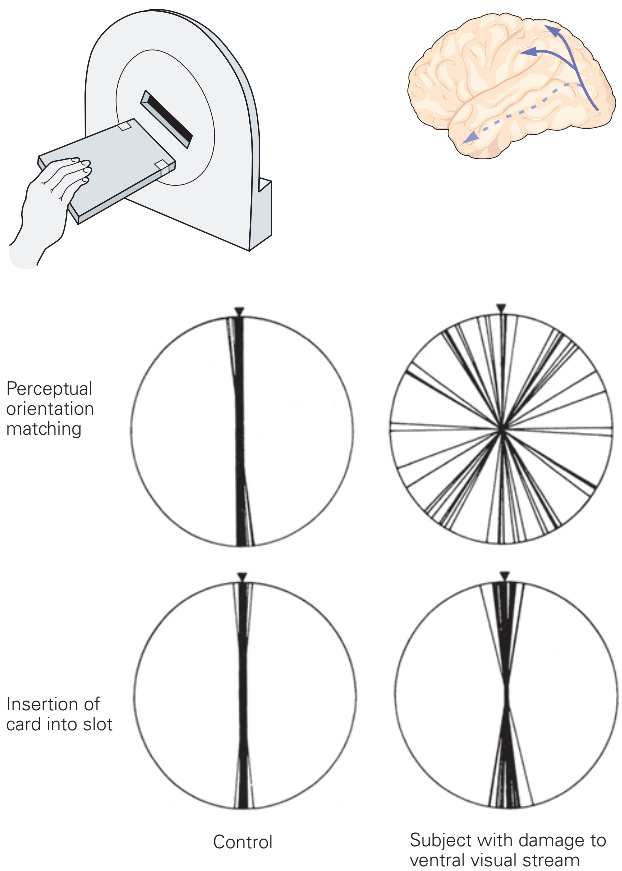

Figure 59–6 Action can be controlled by unconscious stimuli. A patient, D.F., with damage to the inferior temporal cortex, is unable to recognize objects based on their shape (form agnosia). She cannot align the tablet with the orientation of the slot (perceptual matching) because she is not consciously aware of the orientation of either the tablet or the slot. However, when she is asked to put the tablet through the slot in a quick movement, she orients her hand rapidly and accurately. Presumably, the movement is driven by visuomotor computations of which the subject is unaware. (Adapted, with permission, from Milner and Goodale 1995.)

we are vividly aware of being in control of some of our actions—we are aware of a difference between actions that we cause and those that happen involuntarily. Benjamin Libet studied the phenomenon of voluntary action in controlled experiments. He asked his subjects to lift a finger "whenever they felt the urge to do so" and to report the time at which they had this urge. His subjects had no difficulty in reliably reporting the time of this subjective experience. At the same time, Libet used electroencephalography to measure the "readiness potential," a change in brain activity that occurs up to 1 second before a subject makes any voluntary movement. The time at which subjects reported feeling the urge to lift a finger occurred hundreds of milliseconds *after* the beginning of this readiness potential. This result has generated much discussion among philosophers as well as neuroscientists concerning the existence of free will. If brain activity can *predict* an action before a person is aware of having the urge to perform that action, does this mean that our experience of freely willing actions is an illusion?

Although Libet's result has been widely replicated, the relevance of his experimental protocol for our understanding of free will remains controversial. Lifting one finger is not an action that we often perform. Actions usually have goals. For example, we might press a button in order to ring a bell. When our actions are followed by the goal we expect, we feel that we are in control of our actions. It is this subjective experience that gives us a sense of agency, of being the cause of events. Applying Libet's paradigm to such actions, Patrick Haggard discovered the phenomenon of "intentional binding." When a deliberate movement (pressing a button) is followed by its intended goal (hearing a tone), these events are experienced subjectively as bound together in time (Figure 59–7).

This temporal binding of our actions to their goals provides an empirical marker of our sense of agency, since a stronger sense of agency is associated with a greater degree of binding. If a movement occurs passively, caused for example by magnetic stimulation to the brain, then intentional binding is decreased; we actually perceive the time between movement and outcome as longer than the actual physical time.

Our sense of agency is closely linked to our belief in free will and to the idea that people can be held

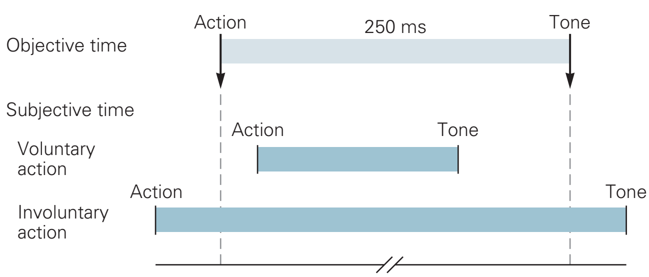

Figure 59–7 We experience our actions and their effects as bound together in time. When subjects are asked to press a button that triggers a sound 250 ms later, they experience their action and the sound as occurring closer together (subjective time) than they actually are (objective time). In contrast, when their finger moves involuntarily through trans cranial magnetic stimulation (TMS) of motor cortex, the movements and the sound are experienced as further apart compared to objective time. Temporal binding occurs only when the movement is intended and deliberate and thus is a marker of the experience of agency. (Based on Haggard, Clark, and Kalogeras 2002.)

responsible for their actions when these are performed deliberately. Intentional binding is increased when associated with outcomes that have moral consequences. It is reduced for actions that have been commanded by others, rather than performed freely. These results do not address the question of whether or not free will exists, but they suggest that our conscious experience of acting freely has a major role in creating social norms of responsibility. Such norms are critical for maintaining social cohesion.

Unconscious inference occurs in the motor domain as well as the sensory domain. Our experience of agency is created from two components: our prior expectations and the sensory consequences of the outcome of the action. We are surprised if the actual sensations do not match what we expect, as when we pick up an object that is much lighter than anticipated (Chapter 30). If the outcome confirms our expectations, however, we pay little attention to the actual sensory evidence—we experience what we expected to happen rather than what actually happened.

Pierre Fourneret and Marc Jeannerod asked subjects to draw a vertical line using a computer's mouse. The subjects could not see their hand and so could not see that the computer created a distortion in the line displayed on the screen. The striking result was that subjects were not aware that they had moved their hand at an angle of 10° to the left to produce the vertical line on the screen (Figure 59–8). This lack of awareness occurred for deviations of up to 15°. When subjects were instructed not to look at the screen but simply repeat the movement they had just made, they did not reproduce the deviant movement they had made but instead drew the straight-ahead movement that they believed they had made. It would seem that as long as the goal is realized (drawing a straightforward line), we experience the expected sensory feedback, not the actual sensory feedback.

This phenomenon helps us understand some otherwise bizarre experiences. For example, after the amputation of a limb, some patients may experience a phantom limb. They still experience the urge to move the missing limb, and they can select specific movements they want the missing limb to make. Their sensorimotor systems predict the proprioceptive sensations they would feel if they were to move an intact limb, and it is these predicted sensations that underlie the sensation of a moving phantom limb.

After a limb has been paralyzed due to stroke, some patients believe that they are still able to move the limb (anosognosia for hemiplegia). Here, again, such patients can select the movements they want to make and are aware of their expectations about the movement. Despite the lack of sensory evidence that follows their attempt to initiate the movement, they believe that the movement did occur.

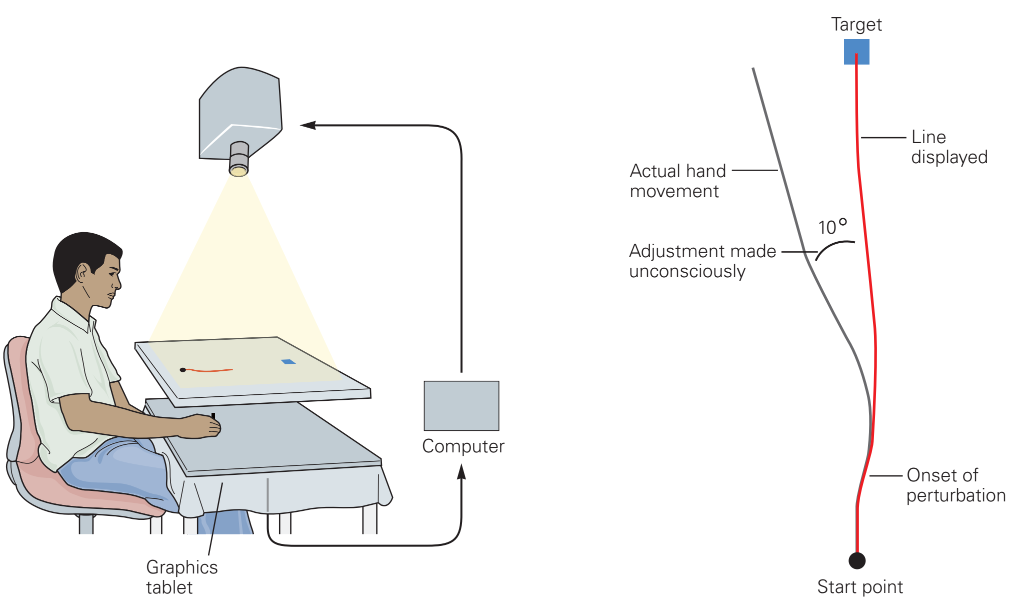

Figure 59–8 Actions can be modified unconsciously. Subjects are asked to draw a straight line with a computer mouse. They can see the line on the screen but not their hand movement. The computer is programmed to systematically distort the line displayed on the screen. In the result shown here, the subject had to move his hand 10° to the left to produce a vertical line on the screen. Subjects are not aware of making such adjustments. (Adapted, with permission, from Fourneret and Jeannerod 1998. Copyright © 1998 Elsevier Science Ltd.)

The Conscious Recall of Memories Is a Creative Process

For most of us, memory is the conscious imaginative reliving of a past experience. If we take no account of subjective experience (the behaviorist stance), however, memory is a process by which our past experience alters future behavior. Our behavior is often affected by past experience, but without conscious recall of the memory or awareness of the influence it is having on us. Once again, this type of experience is seen most strikingly in patients with damage to specific areas of the brain.

Some patients become densely amnesic after damage to the medial regions of the temporal lobe. They show no decline in intellect as measured by IQ tests but cannot remember anything for more than a few minutes. Although devastating, this memory impairment is actually rather circumscribed. The problem is largely manifested in *declarative memory*, and most severely in a type of declarative memory called *episodic memory*, the ability to recollect events in one's life (Chapter 54). *Procedural memory*, in which consciousness has a minor role (Chapter 53), remains intact. Thus, patients can still remember motor skills such as riding a bicycle and can often learn new motor skills at a normal rate. This selective effect of brain damage can lead to dramatic dissociations. A patient who has been learning some new skill every day for a week will deny ever having performed the task before. He is then surprised to find how skillful he has become.

A widely used protocol tests subjects' ability to recall lists of words they have memorized, a task that taps a form of declarative memory. In the recall phase, a subject is presented with a list of the words that were on the study list plus new words. An amnesic patient has great difficulty with this type of task and may misclassify most of the previously seen words as new since she cannot recall seeing them before. Nevertheless, the brain activity elicited by reading old words is different from that elicited by the new words: There is unconscious recognition of a difference, equivalent to that shown by patients with unilateral neglect or prosopagnosia. Normal subjects usually find this task easy, but they too will occasionally misclassify old words as new; as with amnesiacs, evoked brain responses in normal subjects register the distinction lost to conscious recall (Figure 59–9).

Occasionally, a subject misclassifies a new word as an old one. This misclassification amounts to a false memory. Such misclassifications are most likely to occur when the new word is semantically related to one or more of the old words. If the list of old words contained *big*, *great*, *huge*, then the new word *large* is likely to be identified as old. One explanation for this is that the perception of the new word *large* has been unconsciously primed by the previous presentation of the old words. Thus, the new word *large* is processed easily and quickly, and because the subject is aware of this, he concludes the word must be familiar and classifies it as old.

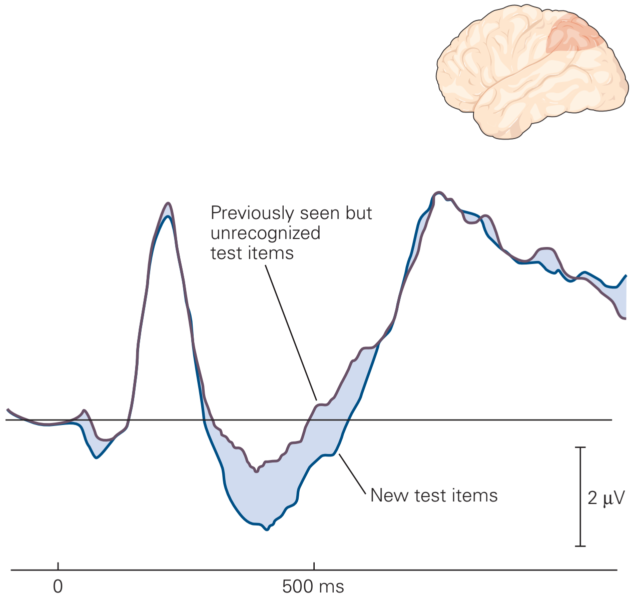

Figure 59–9 Brain activity shows the imprint of forgotten memories. Subjects were presented with a list of words, including some that had been presented earlier and some that were new. When asked to identify the words presented earlier, subjects correctly identified some of the old words but forgot others. Immediately after the visual presentation of a word, there is a brief fluctuation in the evoked potential in the brain. Evoked responses in the parietal region of the brain reflect whether or not the words had been seen before, even when subjects did not consciously recognize the words. The pattern produced by old words, whether recognized or not, is different from that produced by the new words. (Reproduced, with permission, from Rugg et al. 1998. Copyright © 1998 Springer Nature.)

This observation emphasizes that memory is a creative process. Our conscious memories are constructed from both conscious recall and unconscious knowledge. To guard against false memories, as with false percepts, we use our knowledge about the world to determine which memories are plausible.

In some patients, the process by which memories are screened can become dramatically disturbed. If asked what happened yesterday, most patients with amnesia will say that they cannot remember, but a few will give elaborate accounts that do not correspond to reality. Such false memories are called confabulations and can sometimes be extremely implausible. For example, one patient said that he had met Harold Wilson (a former British Prime Minister) and discussed a building job they were both working on.

The creative mechanisms needed to reconstruct memories of past episodes are also involved when imagining events that might happen in the future. In amnesic patients with damage to the hippocampus, the ability to imagine new events is markedly impaired.

Behavioral Observation Needs to Be Supplemented With Subjective Reports

By the middle of the 20th century, it had become clear that the classic behaviorist approach was inadequate for the exploration of many psychological processes. Language acquisition, selective attention, and working memory cannot be understood in terms of relations between stimuli and responses, however complex the relationships postulated.

The demonstration that some cognitive processes are unconscious requires that we move even further from behaviorism. If we want to explore the whole range of conscious and unconscious cognitive processes, we will not be able to do so by focusing on overt behavior alone. We cannot assume that a subject making purposeful, goal-directed actions is necessarily aware of the stimuli eliciting the action or even of the action itself. We must supplement behavioral observations with subjective reports. We have to ask the subject, "Did you see the stimulus? Did you move your hand?"

One hundred years ago, introspection was the major method for obtaining data in psychology. How else could one study consciousness? But different schools of psychology obtained different results and, as John B. Watson emphasized, there seemed to be no objective way of deciding who was right. How can you independently confirm subjective experience? Thus, the method fell into disrepute. During the decades in which psychology was dominated by behaviorism, subjective reports were not considered an appropriate source of data. As a result, methods for recording subjective reports lag far behind methods for recording overt behavior. Regrettably, many studies of cognitive processes still do not require reports of subjective experience from subjects because of the long tradition of excluding such reports.

The one domain of psychology in which subjective reports continued to be used was psychophysics, the study of the relationship between sensation (physical energy) and perception (psychological experience) introduced by Fechner in 1860. Such studies give robust and reliable results and have created some of the few laws in psychology, such as Weber's law (the just-noticeable difference between two stimuli is proportional to the magnitude of the stimuli). In these studies, subjects are typically asked "Did you see the stimulus?" or "How confident are you that you saw the stimulus?"

Signal detection theory, developed in the 1950s, provides a robust methodology for measuring the ability to detect a stimulus (discriminability, d') independently of any reporting biases (Chapter 17). If your discriminability is high, then you will successfully detect small changes in the stimuli. More recently, there has been increasing interest in the second question, "How confident are you that you saw the stimulus?" Reporting one's confidence requires *metacognition*, the ability to reflect on our cognitive processes. This ability has an important role in the control of behavior. For example, if we realize that we are not performing some task very well, we might slow down and pay more attention to what we are doing.

The ability to reflect on our perception can be measured objectively. Likewise, the ability to reflect on the quality of our cognitive processes can also be assessed quantitatively. If your metacognitive accuracy is high, then you will successfully discriminate between your right and wrong answers. In other words, a correct detection will usually be associated with a high degree of confidence, whereas an incorrect detection will be associated with a low degree of confidence. However, your metacognitive accuracy need not be related to your signal detection ability. You could be good at detecting signals while at the same time poor at knowing whether your answers are likely to be right or wrong. In fact, patients with damage to anterior prefrontal cortex retain the ability to detect visual signals but show a marked deficit in metacognitive accuracy.

Verbal reports cannot, of course, be used in signal detection experiments with laboratory animals or preverbal infants. One alternative is to identify aspects of behaviors that reflect confidence. For example, if we are confident that we left our keys somewhere in the living room, we will spend more time looking there before we switch to the hall. Louise Goupil and Sid Kouider applied this insight to the study of metacognition in preverbal infants. The infants had to remember which of two boxes had contained a toy that was later removed without their knowledge. They spent more time searching inside the correct box. The infants were also more likely to ask an adult for help to open the correct box. These effects did not occur after long intervals. This behavior suggests that the infants had some insight into their current state of knowledge. They knew when they could no longer remember which was the correct box. Similar experiments suggest that rats and monkeys also have some metacognitive abilities.

Verification of Subjective Reports Is Challenging

Reports of subjective experience, such as confidence, serve like a meter. Just as an electrical meter converts electrical resistance into the position of a pointer on a dial (reading 100 ohms), so a subject converts a light stimulus into the report of a color ("I see red"). But there is a critical way in which the meter is not like a person. The meter does not experience red and cannot communicate meaning. And, although the meter might be faulty, it can never pretend to see red when it is really seeing blue. Most of the time, we presume that subjective reports are true, that is, the subject is trying as far as possible to give an accurate description of his experience. But how can we be sure that we can rely on these subjective reports?

The problem of verifying subjective reports can partially be addressed with the use of brain imaging. Brain imaging studies have shown that neural activity occurs in localized areas of the brain during mental activity that is not associated with any overt behavior. The content of such mental activity, such as imagining or daydreaming, can be known only from the subject's reports.

If we scan a subject while he says he is imagining moving his hand, activity will be detected in many parts of the motor system. In most motor regions, this activity is less intense than the activity associated with an actual movement, but it is well above resting levels. Similarly, if a subject reports that she is imagining a face she has recently seen, activity can be detected in the fusiform gyrus, the "face recognition area" (Figure 59–10). In these examples, the location of the observed neural activity detected by the scanner

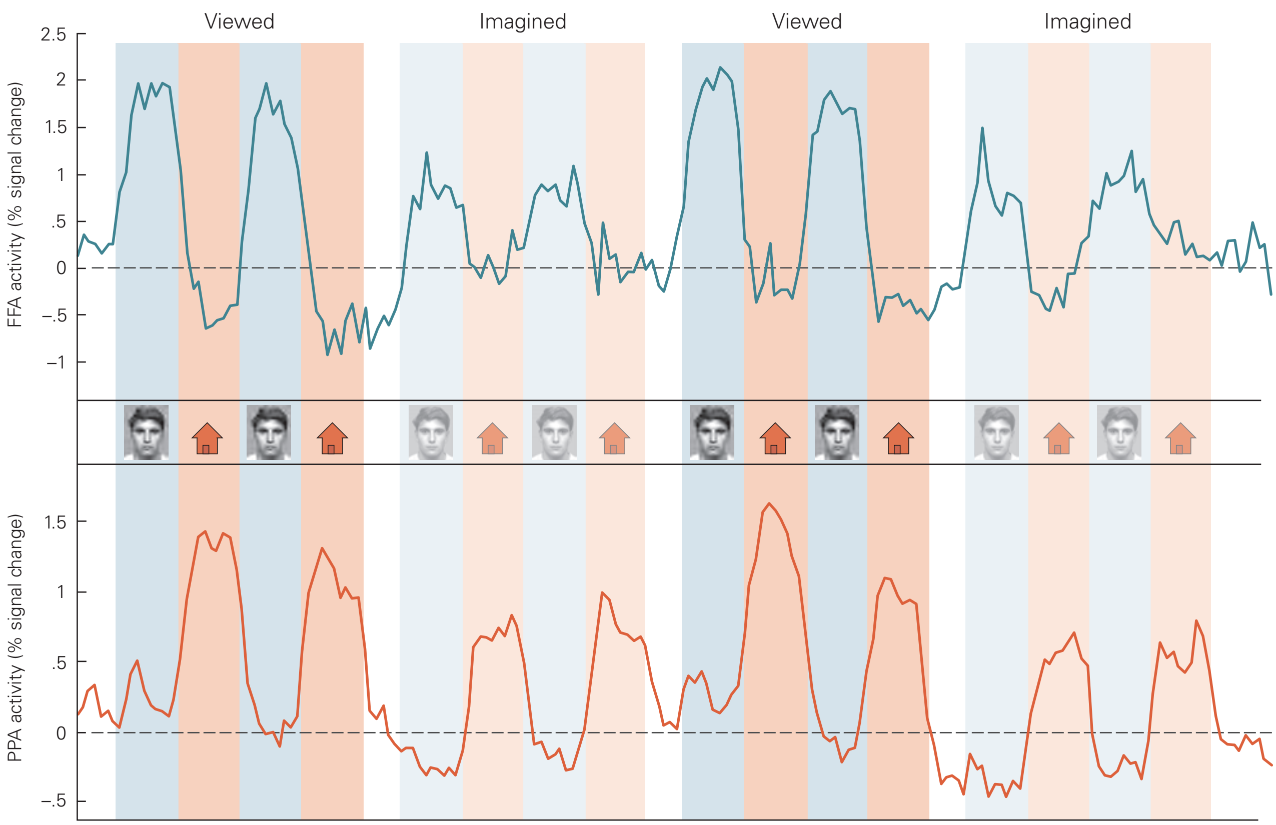

Figure 59–10 Imagining a face or a place correlates with activity in specific areas of the brain. Subjects were scanned while they viewed or imagined faces and houses. In the first block of trials, subjects alternately viewed a face or a house. When viewing a face, brain activity increases in the fusiform face area of the inferior temporal lobe (**FFA**). When viewing a house, brain activity increases in the parahippocampal place area of the inferior temporal cortex (**PPA**). In the next block of trials, subjects alternately *imagined* a face and a house. The same brain regions are active during both the imagining and direct viewing of faces and houses, although the activity is less pronounced during the imagined viewing. (Reproduced, with permission, from O'Craven and Kanwisher 2000. Copyright © 2000 MIT.)