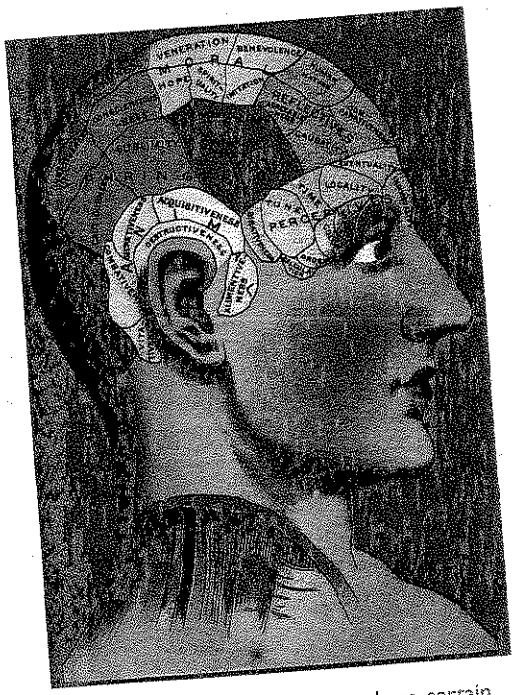
MAPPING THE MIND: THE BRAIN IN ACTION

3.8 Identify different brain-stimulating, -recording, and -imaging techniques.

3.9 Evaluate results demonstrating the brain's localization of function.

Although many questions about the brain remain unanswered, we know far, far more about it today than we did 200, or even 20, years ago. For this, we owe psychologists and related scientists who've developed a host of methods to explore the brain and its functioning a major debt of gratitude. ((•– **Listen** to the Brain Mapping Podcast on **mypsychlab.com**



A phrenologist's chart showing where certain psychological traits are supposedly associated with bumps on the skull.

A Tour of Brain-Mapping Methods

Many advances over the past two centuries have enabled scientists to measure brain activity, resulting in a better understanding of how the most complicated organ in the known universe works. But brain research tools weren't always grounded in solid science. Some of the earliest methods were fundamentally flawed, but they paved the way for the newer and improved methods used today.

PHRENOLOGY: AN INCORRECT MAP OF THE MIND. Phrenology—sometimes jokingly called "bumpology"—was one of the first attempts to map mind onto brain. This theory was wildly popular in the 1800s, when phrenologists assessed enlargements of the skull—literally bumps on the head—and attributed various personality and intellectual characteristics to those who sought their "expertise." Phrenologists assumed that bumps on the skull corresponded to brain enlargements, and that these brain enlargements were linked directly to psychological capacities. From the 1820s through the 1840s, thousands of phrenology shops popped up in Europe and North America. Anyone could go to a phrenology parlor to discover his or her psychological makeup. This popular practice was the origin of the familiar expression "having one's head examined."

The founder of phrenology, Viennese physician Franz Joseph Gall (1758–1828), began with some valid assumptions about the brain. He correctly predicted a positive relationship between enlargements in a handful of brain areas and certain traits and abilities, like language. Nevertheless, the up to 37 different traits that phrenologists described—aggressiveness, vanity, friendliness, and happiness among them—are vastly different from the functions scientists studying the brain today assign to different brain areas. What's more, Gall and others based their hypotheses about the supposed associations between brain areas and personality traits almost entirely on anecdotal observations, which we've learned (see Chapter 1) are often subject to a host of errors.

Still, phrenology had one virtue: It was falsifiable. Ironically, this lone asset proved to be its undoing. Eventually, researchers discovered that patients with damage to specific brain areas didn't experience the kinds of psychological deficits the phrenologists predicted. Even more critically, because the shape of the outer surface of the skull doesn't closely match that of the underlying brain, phrenologists weren't even measuring bumps on the brain, as they'd believed. These discoveries ultimately led to the demise of phrenology as an approach.

falsifiability
CAN THE CLAIM BE DISPROVED?

FACTOID

Mark Twain (1835-1910), often considered America's greatest humorist, once underwent a phrenology reading from Lorenzo Fowler, probably the foremost U.S. proponent of phrenology. Fowler, who was then proponent of Twain's identity, informed Twain that the pattern of bumps on his skull indicated that he had an entirely unremarkable personality with one exception: He lacked a sense of humor. When Twain returned three months later and identified himself, Fowler "discovered" a large skull bump corresponding to humor (Lopez, 2002).

BRAIN DAMAGE: UNDERSTANDING HOW THE BRAIN WORKS BY SEEING HOW IT DOESN'T. New methods quickly arose to fill the void left by phrenology. Foremost among them were methods of studying psychological functioning following damage to specific brain regions. We've already mentioned the pioneering work of Broca and others that linked specific areas of the cerebral cortex to specific functions. More recently, scientists have created lesions, that is, areas of damage, in experimental animals using stereotaxic methods, techniques that permit them to pinpoint the location of specific brain areas using coordinates, much like those navigators use on a map. Today, *neuropsychologists* rely on sophisticated psychological tests, like measures of reasoning, attention, and verbal and spatial ability, to infer the location of brain dysfunction in human patients. Neuropsychological tests, which require specialized training to administer, score, and interpret, include laboratory, computer-

ized, and paper-and-pencil measures designed to assess patients' cognitive strengths and weaknesses (Lezak, Howieson, & Loring, 2004).

ELECTRICAL STIMULATION AND RECORDING OF NERVOUS SYSTEM ACTIVITY. Although early studies of function following brain damage provided valuable insights into which brain areas are responsible for which behaviors, many questions remained. Researchers soon discovered that stimulating parts of the human motor cortex in patients undergoing brain surgery produced extremely specific movements (Penfield, 1958). This finding, among others, led to the hypothesis that neurons use electrical activity to send information. But to test that hypothesis, scientists needed to record electrical activity from the nervous system.

To that end, Hans Berger (1929) developed the **electroencephalograph (EEG)**, a device—still widely used today—that measures electrical activity generated by the brain (see **FIGURE 3.19**). Patterns and sequences in the EEG allow scientists to infer whether a person is awake or asleep, dreaming or not, and to tell which regions of the brain are active during specific tasks. To obtain an EEG record, researchers record electrical activity from multiple electrodes placed on the scalp's surface.

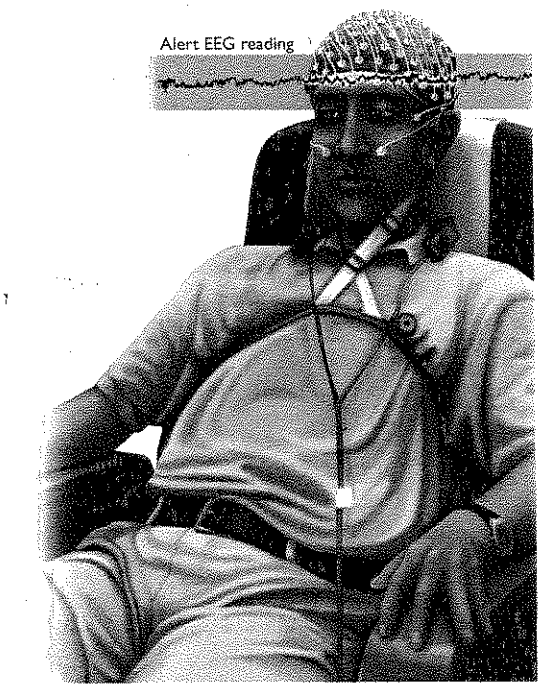


FIGURE 3.19
Electroencephalograph (EEG). An EEG reading during wakefulness.

Because the EEG is noninvasive (that is, it doesn't require us to penetrate bodily tissue), scientists frequently use it in both animal and human studies. EEGs can detect very rapid changes in the electrical activity of the brain occurring in the range of milliseconds (one-thousandths of seconds). Even today, researchers use EEGs to study brain activity in the brains of individuals with schizophrenia, epilepsy, and other psychiatric and neurological disorders as well as those without disorders. But EEGs have a few disadvantages. Because they show averaged neural activity that reaches the surface of the scalp, they tell us little, if anything, about what's happening inside neurons. In this respect, interpreting EEGs is a bit like trying to understand the mental states of individual people in a stadium with 100,000 football fans by measuring how often they cheer, clap, or boo in response to plays on the field; we'll certainly do better than chance, but we'll make lots of mistakes too. EEGs also aren't especially good for determining exactly where in the brain the activity is occurring.

BRAIN SCANS. Although electrical recording and stimulation provided the initial routes for mapping mind functions onto brain areas, a virtual revolution in brain research occurred with the advent of brain scans, or *neuroimaging*. As a group, these imaging methods enable us to peer inside the brain's structure (that is, its appearance), its function (that is, its activity), and sometimes both.

CT Scans and MRI Images. In the mid-1970s, independent teams of researchers developed **computed tomography (CT)** and **magnetic resonance imaging (MRI)**, both of which allow us to visualize the brain's structure (Hounsfield, 1973; Lauterbur, 1973). The CT scan is a three-dimensional reconstruction of multiple X-rays taken through a part of the body, such as the brain. As a result, it shows far more detail than an individual X-ray. The MRI shows structural detail using a different principle. The MRI scanner measures the release of energy from water in biological tissues following exposure to a magnetic field. MRI images are superior to CT scans for detecting soft tissues, such as brain tumors.

PET. CT and MRI scans show only the brain's structure, not its activity. Therefore, neuroscientists interested in thought and emotion typically turn to *functional imaging techniques* like **positron emission tomography (PET)**, which measures changes in the brain's

FICTOID

MYTH: Research using brain imaging is more "scientific" than other psychological research.

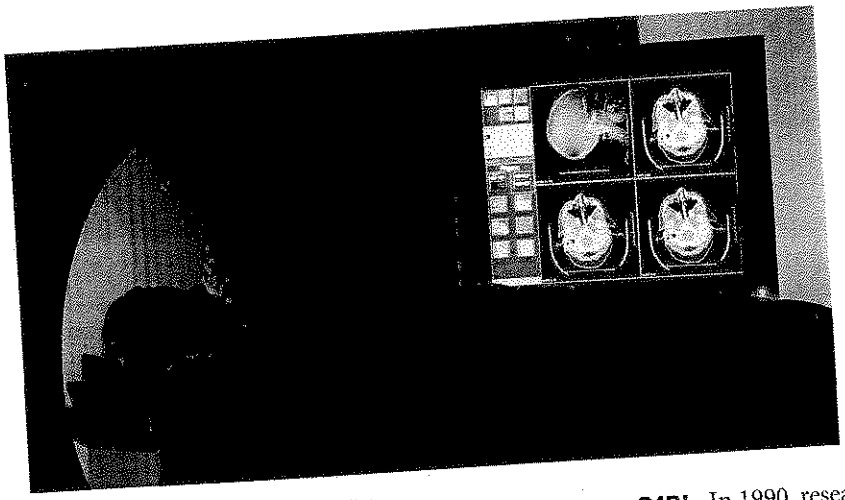
REALITY: Brain imaging research can be extremely useful but, like all research, can be misused and abused. Yet because it seems scientific, we can be more persuaded by brain imaging research than we should be. In fact, studies show that undergraduates are more impressed by claims accompanied by brain imaging findings than research that isn't, even when the claims are bogus (McCabe & Castel, 2008; Weisberg et al., 2008).

electroencephalograph (EEG)
recording of brain's electrical activity at the surface of the skull

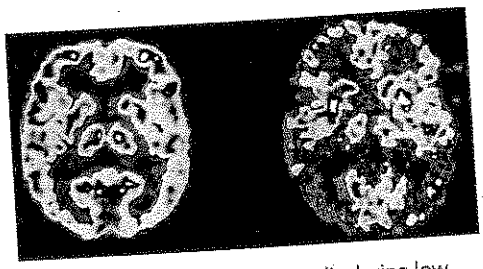
computed tomography (CT)
a scanning technique using multiple X-rays to construct three-dimensional images

magnetic resonance imaging (MRI)
technique that uses magnetic fields to indirectly visualize brain structure

positron emission tomography (PET)
imaging technique that measures consumption of glucose-like molecules, yielding a picture of neural activity in different regions of the brain



Magnetic resonance imaging (MRI) is a noninvasive procedure that reveals high-resolution images of soft tissue, such as the brain.



PET scans show more regions displaying low activity (blue and black areas) in an Alzheimer's disease brain (*right*) than a control brain (*left*), whereas the control brain displays more areas showing high activity (red and yellow).

activity in response to stimuli. PET relies on the fact that neurons, like other cells, increase their consumption of glucose (a sugar) when they're active. We can think of glucose as the brain's gasoline. PET requires the injection of radioactive glucose-like molecules into patients. Although they're radioactive, they're short-lived, so they do little or no harm. The scanner measures where in the brain most of these glucose-like molecules are consumed, allowing neuroscientists to figure out which brain regions are most active during a task. Clinicians can also use PET scans to see how brain activity changes when patients take a medication. Because PET is invasive, researchers continued to work to develop functional imaging methods that wouldn't require injections of radioactive molecules.

fMRI. In 1990, researchers discovered that as neural activity quickens, there's an increase in oxygenated blood in response to heightened demand (Ogawa et al., 1990). The discovery of this response, known as the *blood oxygenation level dependent* (BOLD) response, enabled the development of the **functional MRI (fMRI)**. Because fMRI measures the change in blood oxygen level, it's an indirect correlate of neural activity. Neuroscientists frequently use fMRI to image brain activity in response to specific tasks, like looking at emotional faces or solving math problems (Marsh et al., 2008). The fMRI relies on magnetic fields, as does MRI. fMRI's strength, especially compared with PET, is its ability to provide detailed images of activity in small brain regions and over brief time intervals. Nevertheless, in contrast to PET and some other imaging techniques, fMRI is extremely sensitive to motion, so researchers often have to toss out fMRI data if participants move too much.

MAGNETIC STIMULATION AND RECORDING. **Transcranial magnetic stimulation (TMS)** applies strong and quickly changing magnetic fields to the skull to create electric fields in the brain. Depending on the level of stimulation, TMS can either enhance or interrupt brain function in a specific region. TMS offers useful insights regarding which brain areas are involved in different psychological processes. For example, if TMS interrupts functioning in the temporal lobe and the subject displays (temporary!) language impairment as a result, we can conclude that the temporal lobe is important for language processing. Because it allows us to manipulate brain areas directly, TMS is the only noninvasive brain imaging technique that allows us to infer causation—all other techniques can only *correlate* brain activation with psychological processing. Some reports suggest that TMS provides relief for depression and may decrease auditory hallucinations, that is, the hearing of sounds, typically voices (Saba, Schurhoff, & Leboyer, 2006). *Repetitive TMS* (rTMS) also shows promise as a treatment for depression (Rachid & Bertschy, 2006).

A final imaging technique is **magnetoencephalography (MEG)**, which detects electrical activity in the brain by measuring tiny magnetic fields (Vrba & Robinson, 2001). In this way, MEG reveals patterns of magnetic fields on the skull's surface, thereby revealing which brain areas are becoming active in response to stimuli. MEG's strength is its ability to track brain changes over extremely small time intervals. In contrast to PET and fMRI scans, which measure activity changes second by second, MEG measures activity changes millisecond by millisecond.

How to Interpret—and Misinterpret—Brain Scans. PET, fMRI, and other functional brain imaging techniques have taught us a great deal about how the brain's activity changes in response to different stimuli. They've also helped scientists to uncover deficits in the brain functioning of people with certain psychiatric disorders. For example, they've revealed that schizophrenia, a severe disorder of thought and emotion marked by a loss of contact with reality, is often associated with underactivity of the frontal lobes (Andreasen et al., 1997; see Chapter 15).

Yet it's extremely easy to misinterpret brain scans, largely because many layperson and even newspaper reporters hold misunderstandings of how they work (Racine, Barilan & Illes, 2006). For one thing, many people assume that functional brain images, like the mul

correlation vs. causation

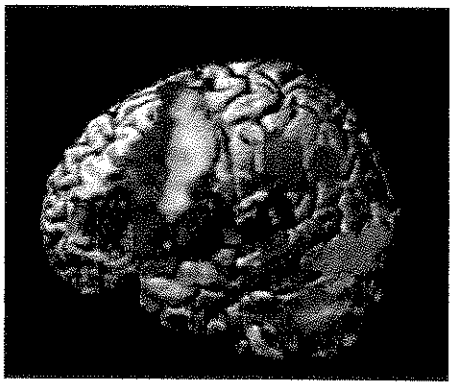
CAN WE BE SURE THAT A CAUSES B?

functional MRI (fMRI)
technique that uses magnetic fields to visualize brain activity using the BOLD response

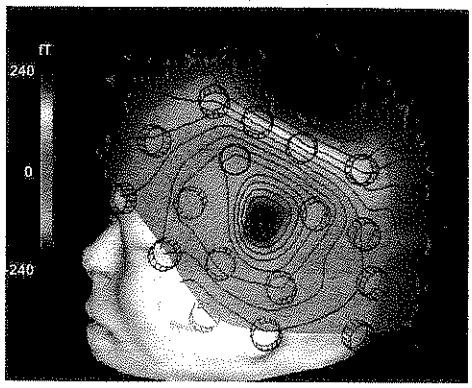
transcranial magnetic stimulation (TMS)
technique that applies strong and quickly changing magnetic fields to the surface of the skull that can either enhance or interrupt brain function

magnetoencephalography (MEG)
technique that measures brain activity by detecting tiny magnetic fields generated by the brain

ticolor images generated by PET and fMRI scans, are like photographs of the brain in action (Roskies, 2007). They aren't. In most cases, these images are produced by subtracting brain activity on a "control" task from brain activity on an "experimental" task, which is of primary interest to the researchers. For example, if researchers wanted to find out how people with clinical depression process sad faces, they could subtract the brain's activity following neutral faces from its activity following sad faces. So although we're seeing one image, it's actually one image subtracted from another. Moreover, the pretty colors in these images are arbitrary and superimposed by researchers. They don't correspond directly to the brain's activity (Shermer, 2008). Making matters more complicated, when a brain area "lights up" on a brain scan, we know only that neurons in that region are becoming more active. They might actually be *inhibiting* other neurons rather than exciting them.



An fMRI of the brain showing areas that were active when subjects remembered something they saw (green), something they heard (red), or both (yellow). (Source: M. Kirschen/Stanford University)



An example of magnetoencephalography (MEG) illustrating the presence of magnetic fields on the surface of the cerebral cortex. (Source: Arye Nehorai/Washington University, St. Louis)

Another complexity is introduced by the fact that when researchers conduct the calculations that go into brain scans, they're typically comparing the activity of hundreds of brain areas across neutral versus experimental tasks (Vul et al., 2009). As a result, there's a risk of chance findings—those that won't replicate in later studies. To make this point, one mischievous team of researchers (Bennett et al., 2009) placed a dead salmon in a brain scanner, flashed it photographs of people in social situations, and asked the salmon to guess which emotions the people were experiencing (no, we're not making this up). Remarkably, the investigators "found" an area in the salmon's brain that became active in response to the task. In reality, of course, this activation was just a statistical artifact, a result of the fact that they'd computed so many analyses that a few were likely to be statistically significant (see Chapter 2) by chance. This finding is a needed reminder that we should view many brain imaging findings with a bit of caution until other investigators have replicated them.

replicability

CAN THE RESULTS BE DUPLICATED IN OTHER STUDIES?

How Much of Our Brain Do We Use?

Despite having so much information available today regarding the relationship between brain and behavior, scores of misconceptions about the brain abound. One widely held myth is that most of us use only 10 percent of our brain (Beyerstein, 1999). What could we do if we could access the other 90 percent? Would we find the cure for cancer, acquire great wealth, or write our own psychology textbook?

The 10-percent myth gained its toehold at around the same time as phrenology, in the late 1800s. William James (1842–1910), one of the fathers of psychology (see Chapter 1), wrote that most people fulfill only a small percent of their intellectual potential. Some people misconstrued James to mean that we only use about 10 percent of our brain. As the 10-percent myth was repeated, it acquired the status of an urban legend (see Chapter 13).

Early difficulties in identifying which brain regions controlled which functions probably reinforced this misconception. In 1929, Karl Lashley showed that there was no single memory area in the brain (see Chapter 7). He made multiple knife cuts in the brains of rats and tested them on mazes. He found that no specific cortical area was more critical to maze learning than any other. Lashley's results were ripe for misinterpretation

A "Fishy" Result? Researchers (Bennett et al., 2009) showed that even a dead salmon can seem to be responding to stimuli—see the red regions of "brain activation"—using standard imaging techniques (to see how, read the text). This finding doesn't show that brain imaging techniques aren't useful, of course, but they show that positive findings can sometimes arise by chance.