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6 Emotion and Motivation: The Cortex Comes to the Party

In this chapter, we'll visit several cortical brain regions that contribute to emotion: the cingulate, the insula, and the orbitofrontal cortex. Early electrical stimulation studies of the brain of patients undergoing neurosurgery revealed that passing weak electrical currents through these sites could elicit feelings and sensations pregnant with emotion, as well as alter physiological responses such as heart rate and pressure, pupil dilation, and respiration, all of which are observed during naturally occurring emotion-laden episodes. We'll see that these regions are interlinked with the amygdala, the hypothalamus, and other brainstem areas that both sense and influence the body.

The Warren Anatomical Museum in Boston is one of the last surviving anatomy and pathology museum collections in the United States. It houses the skull of Phineas Gage, who died in 1860 but whose life-defining moment took place when he was 25 years old: a tamping iron flew through his brain, but he survived to become one of the "great medical curiosities of all time" (Macmillan 2004).[1] Not only has Gage's case become a fixture of psychology and neuroscience textbooks, but he is even known in popular culture for the "personality change" that ensued after the accident. Although the details are murky, Gage is described as hardworking and responsible before the injury, but "fitful, irreverent . . . capricious and vacillating" afterward, as reported by the town doctor, John Harlow, who examined him. Harlow's proclamation that Gage was "no longer Gage" has captured the imagination of medical doctors and scientists alike.

In the nineteenth century, the strong dichotomy between subcortical ("primitive") and cortical ("advanced") brain parts relegated most of emotion to the subcortex. Yet, not entirely, as illustrated by Gage's medical case. The iron rod, all 1.1 meters of it, hit Gage from below, entering the left side of his face in an upward direction, possibly fracturing the cheekbone;

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it passed behind the left eye, through the left side of the brain, and out the top of the skull through the frontal bone.[2] In the early 1990s, using Gage's skull, the damage was investigated with modern imaging techniques to estimate the likely trajectory of the projectile. Although there is dispute whether the lesion affected both sides of the brain or only the left hemisphere, there is no question that the prefrontal cortex was compromised. At the time of the accident, insofar as the behavioral changes were not interpreted to be cognitive, such as those related to language or problem solving, they were deemed to be emotional in essence, thereby strongly implicating the cortex in this type of processing. The ramifications of Gage's lesion for how the brain brings forth the mind had a substantial impact on nineteenth-century thinking.

There's another reason emotion was linked to the cortex in the nineteenth century: consciousness. As we saw in chapter 5, emotion *feels like something*—such as when one is in a rage or in a state of extreme happiness—and, in fact, many researchers consider this property one of its defining properties. Thus, emotion is frequently conceptualized as tied to one of the "highest" components of the mind: conscious awareness. And, to the extent that consciousness and emotion were interlinked, it was natural to conceive of the latter as involving the cerebral cortex, too.

In the United States, William James, the brother of the famous novelist Henry James, was one of the main exponents of psychology as an independent scientific discipline.[3] In a paper published in 1884, James proposed that emotion depends on sensory and motor centers in the cortex. For James, emotion did not depend on separate processes specially devoted to this mental faculty. Instead, it was tied to the changes that occur in the *body* during a triggering event, such as in his famous example of encountering a bear in the woods. For him, then, the feeling of the changes in the body that follow an "exciting fact," as they occur, *is the emotion*. Contemporaneously, the Danish medical researcher Carl Lange outlined a very similar idea whereby emotional events are "brought to consciousness in that they are brought to the centers of taste and vision in the cortex."

We see that early attempts to understand the neurological basis of emotion clearly encompassed the cortex. Nevertheless, these ideas were formulated only in the most general terms, which of course isn't surprising given how little was known about the brain. It would take many decades before the contributions of the cortex to emotion would begin to be elucidated.

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Before delving into the brain sectors discussed in this chapter—the cingulate cortex, the insula, and the orbitofrontal cortex—I offer a reminder. As in chapter 5, the text will keep the areas/sectors largely separate from one another for expository purposes. Again, keep in mind that they work jointly. Chapters 8 to 11 will describe how to put them together in a more principled way.

Electrically Stimulating the Brain

"I was afraid and my heart started to beat," said the patient on the operating table (Vogt 2009, 12).[4] The neurosurgeons had just passed mild electrical stimulation trough the anterior part of the cingulate cortex (figure 6.1). Upon stimulation of similar locations, other patients had reported intense and overwhelming feelings of fear, including one patient who reported a sensation so intense as to be described as the feeling of imminent death. How could patients describe their experience in the middle of neurosurgery? As it happens, because the brain contains no pain sensors, the procedure is frequently performed under local anesthesia, and patient feedback is invaluable.

That the human cortex is electrically excitable was first established by Roberts Bartholow in 1874, soon after the experiments by Fritsch and Hitzig using dogs (see chapter 4).[5] Bartholow stimulated the cortex of a dying "feeble-minded" girl whose brain was ulcerated so badly that her pulsating brain could be seen (incisions had already been made to allow the pus to

Figure 6.1
The cingulate cortex is shown in a darker shade along the medial surface of the brain.

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escape). He found that, upon stimulation, she moved her limbs and felt tingling sensations, both on the opposite side of her body. Although Bartholow felt that he could introduce needles into the patient's brain "without material injury," he was severely criticized in both the United States and Europe for conducting such an experiment on a person.

Harvey Cushing, who was quoted in the context of the hypothalamus in chapter 3, was one of the pioneers of electrical stimulation during neurosurgery in the beginning of the twentieth century. Such work wasn't performed out of scientific curiosity but to aid in the planning of the operation, which was then performed to remove tumors or sites generating epileptic seizures. To the extent possible, surgeons sought to avoid removing cortical tissue producing language or controlling bodily movements, for example. Because the borders of this type of tissue can shift spatially a little from person to person, surgeons stimulated the brain during the operation to test potential involvement in these functions. During this period of technical improvements, ethical standards advanced modestly. For example, Otfried Foerster (1931, 310), one of the leaders in this area, said: "Strong faradic [electrical] stimulation produces a convulsion, which may be limited to the eye muscles, but in other cases other movements occur." Clearly, the ethical concerns for patients left much to be desired. (Of course, in no way was the horrific treatment of animals, especially in the nineteenth century, acceptable either. The ethics of animal experimentation is a complex subject that continues to evolve.)

It was the neurosurgeon Wilder Penfield, together with his collaborators, who took the technique of electrical brain stimulation to the next level scientifically. Early in his career, Penfield was a surgical intern under Harvey Cushing himself. Because neurosurgery can be performed, as mentioned, under local anesthesia, patients can report sensations and feelings when stimulated in different parts. By exploiting the information thus garnered, Penfield and his colleagues generated detailed "functional maps" of the cortex across hundreds of patients summarizing the type of experience reported at each stimulation site. Their most famous discovery was the "homunculus" (Latin for "little person") first reported in 1937 and refined in 1950. The homunculus map is a grotesquely distorted outline of a body superimposed on a sketch of the top of the brain, depicting locations where stimulation produces sensory or motor effects (figure 6.2). The relative proportions of the body parts of the drawing (hand, foot, and so on) indicate

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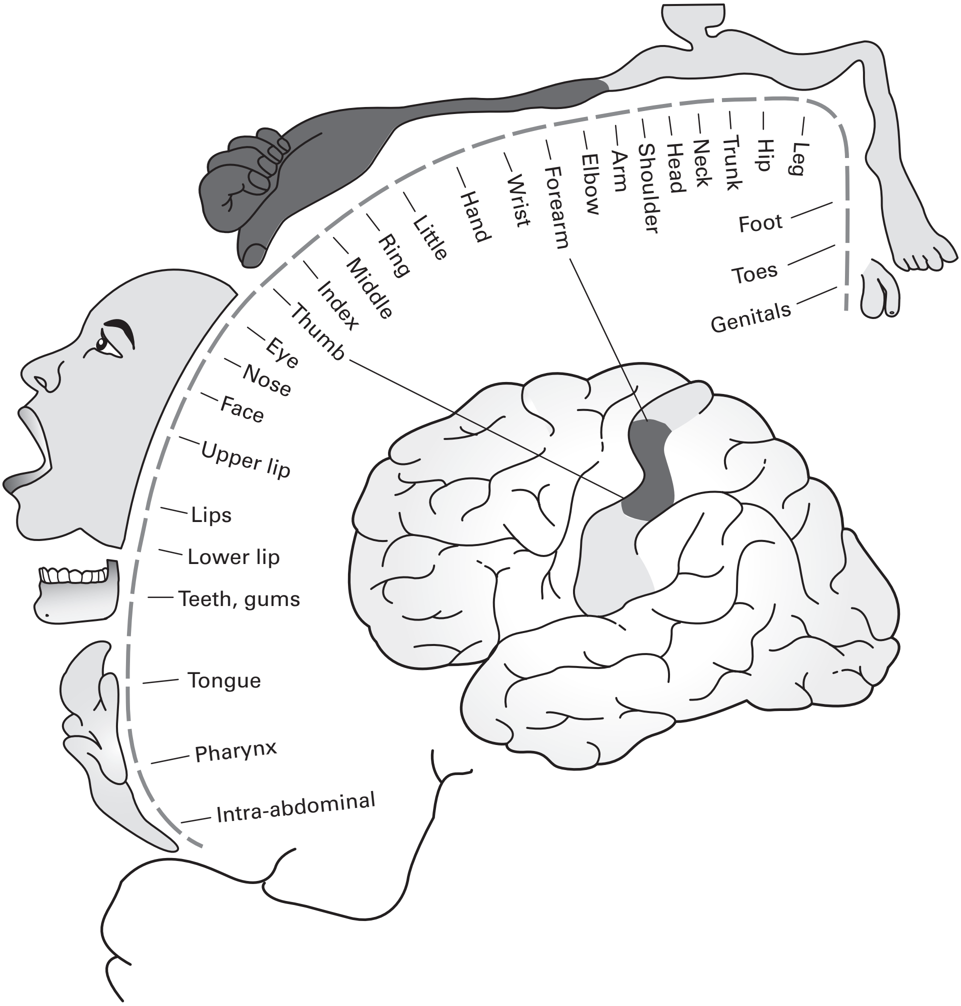

Figure 6.2
The so-called homunculus along the lateral surface of the somatosensory cortex in the parietal cortex. The parts corresponding to the foot, toes, and genitals are situated along the medial part of the brain, not visible from this side view.

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the relative sizes of the regions whose stimulation influences the corresponding body parts. For example, the hands of the homunculus are much larger than the shoulder because the brain tissue where stimulation produces responses in the former is much larger than that where stimulation produces responses in the latter. And homuncular genitals are drawn next to the feet to indicate the relative positions of their cortical gray matter.

As we noted earlier, electrical stimulation of the cingulate cortex is, at times, accompanied by emotional experiences. But even before this type of evidence was obtained during neurosurgery, this cortical sector was among the first suggested to play a role in emotional processing, pretty much based on a hunch. In a landmark paper published in 1937, the neuroanatomist James Papez ventured that the cingulate gyrus was the cortical centerpiece of the "emotional brain," a cortical-subcortical circuit specialized for emotion. Whereas at the time there was little to indicate a link between the two, Papez cited medical cases of tumors in this region associated with "change in personality or character" and "loss of spontaneity in emotion" to back up his proposal (actually, not unlike Gage's purported changes, although his lesion was substantially more frontal, just behind the bones of the eyes). It was hardly solid evidence, given that clinical cases are rarely clean; more often than not, lesions are large or diffuse and damage multiple sites. So why did Papez choose the cingulate cortex as the cortical anchor of his emotion circuit?

In 1878, Paul Broca—the very same who examined Tan and localized language to the left frontal cortex (see chapter 4)—published a hugely influential manuscript with an unwieldy title: *Comparative anatomy of the cerebral circumvolutions: The great limbic lobe and the limbic fissure in the mammalian series*.[6] Broca proposed the existence of a "great cerebral cortical system" that encircles the limbus (or edge) of the hemispheres. At the broadest level, he subdivided the cortex into two components: the *great limbic lobe*, comprising the bulk of the medial surface of the cortex (essentially the cingulate cortex as shown in figure 6.1), and the rest of the cortex—the rest being all of the cortex that is visible from outside (frontal, parietal, occipital), plus the cortex of the insula (discussed in the next section). Broca believed that the brain of primates was qualitatively different from that of other animals because of the "predominance of the frontal lobe," as he stated. This frontal dominance was accompanied by another significant change: the atrophy of the olfactory system. What's more, these two changes were not accidental

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but reflected a "true correlation": the enlargement of the frontal lobe and the devolution of the great limbic lobe.

Although Broca's observations were anatomical in nature, they were intimately connected to his thinking about mental functions. For him, the sense of smell was a *bestial* one that required only slight "intellectual involvement" and relied on the limbic lobe, a cortical sector that ranked low in the cerebral totem pole. Intelligence gained supremacy over the bestial sense by the elaboration of the frontal lobe and the concomitant atrophy of the limbic sector. The impact of Broca's ideas were enormous, and one can venture that the concept of a "limbic brain" has been one of the most influential concepts in all of neuroscience. This was his second major scientific home run, the first being the paper about the localization of the language mental faculty. The upshot? After Broca, it was natural to link the cortex along the medial surface of the brain with emotion (often equated with the bestial or irrational side) and the "outer" parts, especially the front, with cognition (the rational side).

Let's return to Papez and his outline of an emotion circuit. Papez's proposal was further extended by Paul MacLean, whose ideas about the "emotional brain" reverberate to this day. In 1949, MacLean wrote a paper introducing the "visceral brain," which he dubbed the "limbic system" a few years later. The system was composed of the great limbic lobe of Broca (that is, the cingulate gyrus along the medial surface of the brain), together with select subcortical regions, of which the hypothalamus was given particular importance because of the work by Bard, Cannon, and their contemporaries (chapter 5). MacLean's limbic system established an emotional brain that was largely segregated from parts believed to support reason, echoing a dichotomy with a long history in Western thinking.

Some of the Functions of the Cingulate Cortex

In the 1940s, electrical stimulation studies in both primates and humans started to uncover that multiple sectors of the cortex—not only subcortex—elicited autonomic system changes. Striking changes in respiration, blood pressure, heart rate, and pupil dilation resulted when stimulating the cingulate gyrus. Changes in vocalization were also observed, which is notable given that such changes are present during emotional and motivational states in particular—think of the aggressive pants of a gorilla or the

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appeasing sounds of a chimpanzee; vocalization is invariably altered when humans are emotionally aroused, too.[7] The autonomic changes on engagement of the cingulate cortex are entirely consistent with its anatomical connectivity given that it projects to multiple structures outside the cortex that participate in autonomic processes. These pathways target the hypothalamus at the base of the forebrain, the periaqueductal gray (PAG), and other upper brainstem areas, as well as to structures in the medulla. The cingulate cortex thus influences multiple levels across the neuroaxis.

Indeed, the potential for the cingulate cortex to alter the state of the body is remarkable, as this cortical territory has the most extensive "descending" projections (those directed at non-cortical structures) of any other part of the cortex (figure 6.3).[8] Therefore, it is not surprising that this cortex is often viewed as an outflow, or motor, station. Nevertheless, the cingulate receives "ascending" signals from the brainstem. One of the most notable of these is from a nucleus in the medulla that is the major viscerosensory cell group in the brain. The area, called the nucleus of the solitary tract, receives inputs from the respiratory, cardiovascular, and gastrointestinal systems. Signals from pain-sensitive circuits also reach the cingulate through the thalamus. Overall, the cingulate cortex participates in two-way signal communication: not only does it participate in motor autonomic functions affecting the body, but it is sensitive to signals that convey the state of the body, too.

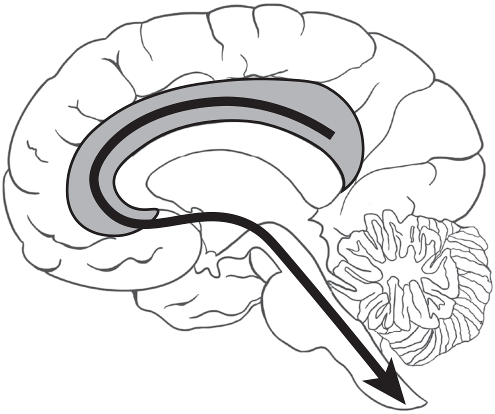

Figure 6.3

Descending connections from the cingulate cortex branch out at multiple levels, reaching subcortical structures at the base of the forebrain, midbrain, pons, and medulla.

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Appraisal refers to the evaluation of an internal or external stimulus, and those that are significant induce an emotional reaction, the magnitude, duration, and quality of which result from the appraisal process. Functional MRI research indicates that responses in the cingulate cortex reflect appraisal.[9] For example, in studies in which participants were asked to rate the aversiveness of objects that were paired with mild shock, cingulate responses were positively correlated with participants' ratings; those that indicated that the object was more aversive exhibited stronger fMRI signals (figure 6.4).

(The use of mild shock may conjure thoughts of dreadful experiments performed by psychologists in the past, or even perhaps scenes from horror movies. However, modern experiments with mild electrical stimulation performed during functional MRI scanning [or outside of the scanner] employ stimuli that are well tolerated by the majority of participants. In studies in my laboratory, for example, participants determine their own level of stimulation by increasing and decreasing the intensity themselves, until attaining a level that is uncomfortable but not painful. Although the stimulus is clearly unpleasant, there is no other way to study negative emotion without participants experiencing something that is, well, unpleasant. But obviously this must be done in an ethical manner, with consenting adults. Participants are free to discontinue the experiment at any time. In well over a decade of performing such experiments, participants in my lab have stopped participation very few times.)

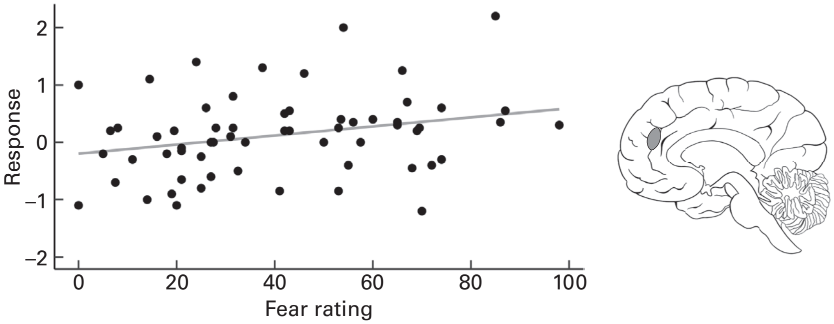

Figure 6.4

Ratings of aversiveness are correlated with responses in the cingulate cortex brain region (indicated in the line drawing of the brain). In the experiment, participants rated the aversiveness of objects previously paired with mild shock.

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We saw in chapter 5 that the amygdala plays a major part in fear conditioning: The pairing of an initially neutral stimulus with an intrinsically aversive item leads to the once-neutral item acquiring negative properties. But what happens if the conditioned stimulus is no longer paired with the aversive item? For example, a sound that was paired with shock is now presented by itself. If this keeps on happening, it signals that the conditioned stimulus no longer predicts the unconditioned one. Naturally, it behooves the animal to learn that the stimulus is again neutral, a process called *extinction learning*. Interestingly, learning that a conditioned stimulus no longer forecasts an aversive event is not a passive, decay-like process of forgetting the previous fear memory. Instead, it is an active learning process in itself and needs to be sufficiently established for the animal to cease reacting to the neutral stimulus—which would be clearly maladaptive now that the stimulus is harmless. Extinction learning, which one can intuit has important implications for the understanding of clinical conditions such as anxiety, has been extensively studied. Several brain structures participate in this process, with the cingulate cortex being an important one. We'll return to extinction learning in a lot more detail in chapter 11.

The anterior part of the cingulate cortex is also linked to pain. Persistent pain is measured by means of self-report—a patient reports feeling back pain, say, and that it prevents her from playing tennis as she used to. Given the prevalence of pain-related conditions in the population at large, researchers have sought "objective markers" of this affliction—something akin to a blood test for a condition like diabetes. In a series of neuroimaging studies examining a large number of participants, Tor Wager and his collaborators (2013) found multiple brain regions, including the anterior cingulate cortex, whose signals are correlated with subjective discomfort levels: the higher the subjective level of pain, the stronger the response in this area.

These researchers sought to develop an objective measure of pain by using computational techniques from the field of machine learning. By way of analogy, consider the goal of recognizing images. After the algorithm is set up, an arbitrary image is provided as input and a label is generated as output, with the latter indicating the category of the input image—for example, "leopard" indicating the stimulus category. These algorithms are initially trained with a large number of sample images and then tested with novel ones. In what's called "supervised training," the machine learning

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algorithm is calibrated by providing images together with their known labels; the "supervisor" thus needs to know their identities.

Wager and colleagues adopted a similar approach to their functional MRI data.[10] In their experiment, a participant received noxious heat during the painful condition; as a control, at other times they experienced innocuous warmth. They trained their algorithm to associate responses across brain areas with the condition in question. Based only on the brain responses during a specific experimental condition, the machine learning method generated its own prediction ("painful" versus "non-painful"). Their technique performed very accurately and exhibited sensitivity and specificity of 94 percent or higher when data from novel participants were provided. (Sensitivity refers to the "true positive" rate—that is, deciding "painful" when the input is painful; specificity refers to the "true negative" rate, or deciding "non-painful" when the condition is non-painful.) In other words, when tested with data never seen by the machine learning algorithm, the method was able to guess the experimental condition by inspecting brain responses—a type of "brain reading" (figure 6.5). Even more impressively, the researchers could predict actual pain ratings; in this case, they trained their algorithm to estimate the continuous pain rating (on a scale of 0 to 8). Actual and predicted pain levels showed a strong match. When a participant rated the

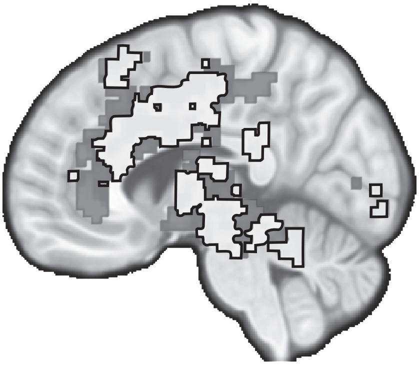

Figure 6.5
Contributions of brain areas to predicting pain. Stronger responses in areas indicated in light gray, including a large part of the cingulate cortex, predict pain states. They also predicted participants' numerical ratings of pain. Stronger responses in areas in darker gray predicted less pain.
Source: Image kindly provided by Tor Wager.

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pain as higher intensity (closer to 8), the algorithm did so too; when they rated it as lower intensity (closer to 0), the method, on average, did the same. Overall, the approach by Wager and colleagues represents an exciting direction of research; it is rare to see such a quantitative angle in a field that is largely qualitative, even more so when targeted at something as subjective as how pain feels. No small feat.

Before moving to the next section, I'd like to discuss the enduring legacy of Papez's circuit and the limbic system idea, both of which tried to explain how emotion is organized in the brain. Although the term "limbic system" is probably one of the most broadly used in neuroscience, the concept has proved too unwieldy and unstable to be scientifically useful. (The terms is extremely popular in the general media, too; a search in the *New York Times* returned more than 200 hits.) Because agreement regarding the regions that belong to this system has never been attained, the term is used in a circular fashion to indicate the "emotional brain." As some have pointed out, "limbic system" substitutes naming for understanding.[11] Unfortunately, the term remains all too commonly employed by investigators, particularly those with more clinical or medical training. Indeed, it is somewhat baffling that medical texts describing the brain basis of emotion still discuss the limbic system in ways that go back to the original proposal by MacLean, if not all the way back to the circuit of Papez, although both of them reflect current knowledge rather poorly.

The Island of the Cortex

The external world impacts areas of the cortex that respond to visual, auditory, tactile, olfactory, and gustatory stimulation. As much as the world outside is rich in information, there is an equally luxuriant inner realm that pertains to the state of the body, including the soft internal organs, the viscera, and the body's outer layer, the skin, which is the largest organ of the body. A wide gamut of signals supports sensations related to temperature, pain, itching, tickling, sensual touch, muscular and visceral impressions, vasomotor flush (the sensation of sudden flushing and sweating), thirst, hunger, even "air hunger" (try holding your breath for 30 seconds). The cortex of the insula registers the state of the body in a precise and signal-specific fashion—it is a sophisticated sensory cortex (figure 6.6).

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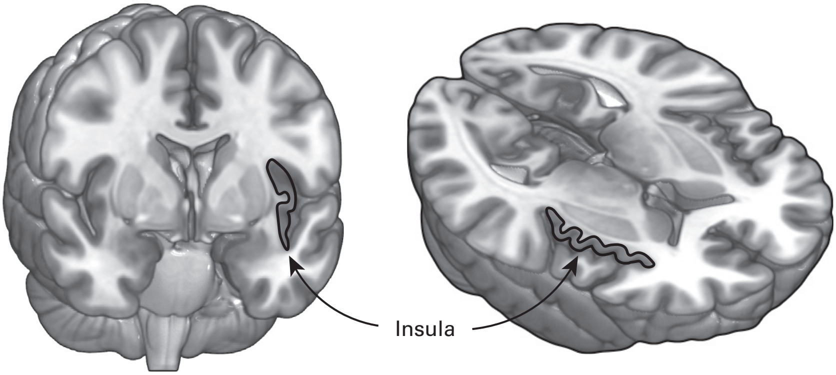

Figure 6.6
The cortex of the insula is visible when the brain is cut, thereby exposing the "internal cortical island."

Viscerosensory signals from the body reach the lower brainstem before eventually reaching this peculiar part of the cortex. Like an island, and covered by cortical tissue itself, the insula is not visible from the outside (if the brain were exposed and one were looking from the side). It is as if the cortical surface had decided to expand by creating a second cortical fold on top of the inner one (the insula); in fact, part of the cortex covering the insula is called "operculum," meaning "lid" in Latin.

Early hints that viscerosensory signals reach the cortex go back to the 1950s, when researchers stimulated the vagus, a large nerve exiting the brain that innervates the heart, the stomach, and intestines. When investigators stimulated the vagus nerve in monkeys and other animals, they noted activation of a "vagal receptive cortex" corresponding to the insular cortex. The role of the insula in the conscious appreciation of visceral sensation was vividly demonstrated in the studies by Penfield and colleagues, as they electrically stimulated the cortex of patients during neurosurgery.[12] As Penfield moved the electrode down along the primary sensory cortex, he identified a region extending just beyond the tongue in the homunculus, where electrical stimulation produced taste sensation. When he moved the electrode further into the insula, the patients reported oropharyngeal, esophageal, or even gastrointestinal sensation. Whereas the patients volunteered a variety of descriptions about their experiences, none of them reported emotional responses—they were more of a sensory nature. We

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now know that both sympathetic and parasympathetic bodily signals are conveyed to the insula. In fact, anterior insula responses reflect the internal state of the body along all of the dimensions outlined before, in a very real sense generating a map of "feelings from the body."[13]

We are in constant synergy with our surroundings, and touch is an important but often neglected component of such interactions. Touch helps acquire information about textures and shapes, aiding inferences about material properties and object identity. Touch also possesses an affective component; some experiences are pleasant (soft brush stroking, say) while others are unpleasant (stroking with sandpaper). Touch promotes affiliative, collaborative, and sexual behavior, too. Tactile social interactions even benefit mental and physical health. Lesion studies have demonstrated that the insula is important for different forms of touch sensation, including inferring sensory pleasure and emotion-related dimensions of the stimulation. And, for example, soft brush stroking produces functional MRI responses in the insular cortex (as well as in the somatosensory cortex; see figure 6.2).

By and large, researchers treat the insula as an autonomic sensory *input* station, in contrast to the suggested "motor," or output, autonomic role of the cingulate cortex. But, as we saw, the cingulate receives viscerosensory signals, too, so it participates in sensory processes in addition to participating in prominent output functions. The insula also contains descending projections that affect the body.[14] Thus, in both the cortex of the cingulate and the insula, *bidirectional* communication exists, albeit with asymmetrical efficacies.

In one of my early functional MRI studies, we sought to understand the mechanisms supporting good performance in a challenging cognitive task (Pessoa et al. 2002): How do participants maintain in mind for a few seconds a briefly presented visual pattern? Although the context was rather different, our approach was similar to the one employed by Wager and colleagues to study pain. Remember that, by using responses across brain regions, they attempted to predict if the participant was in a painful or non-painful state. In our case, the goal was to use brain signals to predict if the participant performed correctly or not in a given trial. Given that the task was effortful and stimuli were visual in nature, we weren't entirely surprised that signals in visual cortex and regions important for cognitively demanding tasks could be used to predict performance. In addition to these regions, we found that signals in the anterior insula closely correlated with task behavior. When discussing these findings, I remember that my colleagues

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and I were puzzled about this region's involvement during a cognitive task. Indeed, for several decades following the seminal studies of functions of the insular cortex, this cortical lobe was regarded largely as a viscerosensory part of the brain.

When MRI machines became more accessible worldwide in the late 1990s, researchers started observing responses in the insula during experimental conditions containing emotionally evocative stimuli, such as viewing pictures of a mutilated body. These responses were expected, as seeing such stimuli produce bodily sensations (imagine yourself viewing a picture of mutilation, perhaps from a medical text). But, gradually, functional MRI studies started to paint a different picture when responses in the insula were observed consistently in tasks spanning perceptual and cognitive conditions, much like I observed in the study of task performance.

During most functional MRI studies, the entire brain is scanned. So, even if an investigator has a pet theory that certain conditions evoke responses in particular brain regions, given that brain-wide data are collected, unexpected findings arise more readily. When more and more studies reveal a consistent pattern of results, the strength of the evidence grows accordingly. Indeed, when my colleagues and I performed the large-scale analysis of thousands of neuroimaging studies (discussed in chapter 4), the anterior insula was among the most *functionally diverse* regions of the entire brain (Anderson, Kinnison, and Pessoa 2013). Responses were observed across studies of perception, cognition, emotion, motivation, and action, suggesting that this area is much more than a dedicated viscerosensory sector—it participates in a very broad range of processes. To date, we still know little about *how* the insula contributes to such varied mental functions.

The Cortex above the Eyes

At age 35, patient EVR underwent neurosurgery to treat a meningioma, a slow-growing tumor that forms from the meninges, the membranes surrounding the brain.[15] Following recovery, EVR exhibited profound personality changes. His marriage had been stable and successful; after surgery, he divorced his wife of many years and within months remarried, but the marriage was short-lived. Previously with a keen sense of business, EVR attained considerable financial success; after his surgery, he entered into a series of brief but disastrous business ventures, one of which led him to bankruptcy. He had been an accomplished professional, securing promotions for good

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performance; afterward, he was not able to maintain employment, ultimately having to live in a sheltered environment. You might think that EVR was simply not "intelligent enough" anymore to be successful professionally, and that even his personal life was affected by this change. But that doesn't explain his difficulties. After the surgery, he was an avid conversationalist that often came across as intelligent, charming, and witty. In standardized tests, he scored more than two standard deviations above the mean (IQ = 135, where the mean is centered at 100). So, he was skilled and "intelligent enough" to hold a job.

The surgery on patient EVR excised a part of the frontal lobe called the orbitofrontal cortex, which sits just above the orbits of the eyes and extends back a few centimeters forming the frontal base of the brain (figure 6.7). The personality alterations that he experienced are similar to those attributed to Phineas Gage discussed earlier in the chapter. Although Gage's character changes now seem to have been somewhat transient and largely inflated (at some point, Gage actually became a successful long-distance stagecoach in Chile), patients like EVR demonstrate that comparable "personality transplants" can occur. Patients such as EVR do not exhibit drastic modification of emotional behaviors; for example, they don't necessarily become severely depressed, although they may experience anger more frequently than before. Instead, the patients often become emotionally "shallow," experiencing an overall dampening of affect. And in some cases they become callous to the point of exhibiting what's called "pseudopsychopathy." Because the condition results from brain impairment, it has also been dubbed "acquired sociopathy" to highlight the fact that it results from the injury and to distinguish

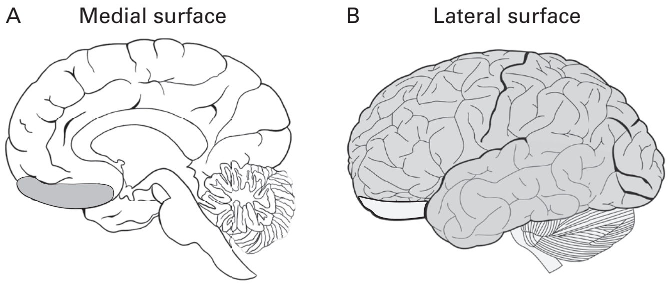

Figure 6.7

The orbitofrontal cortex seen from the middle (a) or side (b) of the brain. This cortex sits just above the orbital bone and eyes and extends further inward into the brain.

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it from conventional psychopathy, in which the cold-blooded traits emerge in childhood and adolescence with no gross structural brain changes.[16] Although there are many ways to define psychopathy, in broad terms, it's a personality disorder displaying persistent antisocial behavior, impaired empathy and remorse, and bold, disinhibited, and egotistical traits.

We discussed earlier in the chapter how the cingulate cortex and the insula are involved in autonomic processes. The same early wave of studies using electrical stimulation of cortical sites revealed the participation of the orbitofrontal cortex in these functions, too—for example, changes in respiration, blood pressure and heart rate, and pupil diameter. Today, much of the research on the orbitofrontal cortex aims at understanding how it contributes to the processing of rewards and, more generally, the computation of value. For instance, what is better for me now—to continue reading this book or to go out with some friends? We'll come back to these questions in chapter 10.

Coda

Early thinking in neuroscience was heavily influenced by the social and biological notions of Victorian England, where concepts such as progress, hierarchy, and control were much in vogue to justify the enrichment of a subset of society. In this context, the brain was viewed as comprised of "primitive" and "advanced" parts, with the subcortex and cortex existing as paradigmatic representatives of these two types of territory. Yet, by the 1950s, the participation of the prefrontal cortex in autonomic processing had been conclusively demonstrated. The crown jewel of "rational" processing was also bidirectionally involved in respiratory, cardiovascular, and even gastric mechanisms, all "lowly functions," including the lowest of them all. Every neuroscience textbook or book about the brain describes how parts of the cortex are important for handling the external world—vision in the occipital lobe, audition in the temporal lobe, somatosensation in the parietal lobe. But the cortex is equally important for taking care of the internal world of the body. Modern research emphasizes the involvement of the prefrontal cortex in the "highest functions"—planning, manipulation of information, prioritization of behaviors, and so on—to such an extent that its participation in monitoring and controlling the body is often forgotten. This view is shortsighted: complex behaviors involve a close interaction between the internal and external realms.

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This is a section of doi:10.7551/mitpress/14636.001.0001

The Entangled Brain

How Perception, Cognition, and Emotion Are Woven Together

By: Luiz Pessoa

Citation:

The Entangled Brain: How Perception, Cognition, and Emotion Are Woven Together
By: Luiz Pessoa
DOI: 10.7551/mitpress/14636.001.0001
ISBN (electronic): 9780262372107
Publisher: The MIT Press
Published: 2022

The open access edition of this book was made possible by generous funding and support from MIT Press Direct to Open

The MIT Press

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The MIT Press would like to thank the anonymous peer reviewers who provided comments on drafts of this book. The generous work of academic experts is essential for establishing the authority and quality of our publications. We acknowledge with gratitude the contributions of these otherwise uncredited readers.

This book was set in Stone Serif and Stone Sans by Westchester Publishing Services.

Library of Congress Cataloging-in-Publication Data

Names: Pessoa, Luiz, author.
Title: The entangled brain : how perception, cognition, and emotion are woven together / Luiz Pessoa.
Description: Cambridge, Massachusetts : The MIT Press, [2022] | Includes bibliographical references and index.
Identifiers: LCCN 2021061878 (print) | LCCN 2021061879 (ebook) | ISBN 9780262544603 (paperback) | ISBN 9780262372107 (pdf) | ISBN 9780262372114 (epub)
Subjects: LCSH: Perception. | Emotions and cognition. | Brain. | Neuropsychology.
Classification: LCC BF311 .P3767 2022 (print) | LCC BF311 (ebook) | DDC 153—dc23/eng/20220411
LC record available at https://lccn.loc.gov/2021061878
LC ebook record available at https://lccn.loc.gov/2021061879

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