3. LOOKING INTO THE BRAIN: THE NEUROSCIENCE REVOLUTION

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CHAPTER 3
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If we could look through the skull into the brain of a consciously thinking person, and if the place of optimal excitability were luminous, then we should see playing over the cerebral surface, a bright spot, with fantastic, waving borders constantly fluctuating in size and form, and surrounded by darkness, more or less deep, covering the rest of the hemisphere.
—Ivan Pavlov
You observe a lot by watching.
—Yogi Berra
n the early 1990s novel brain-imaging techniques opened up undreamed-of capacities to gain a sophisticated understanding about the way the brain processes information. Gigantic multimillion-dollar machines based on advanced physics and computer technology rapidly made neuroscience into one of the most popular areas for research. Positron emission tomography (PET) and, later, functional magnetic resonance imaging (fMRI) enabled scientists to visualize how different parts of the brain are activated when people are engaged in certain tasks or when they remember events from the past. For the first time we could watch the brain as it processed memories, sensations, and emotions and begin to map the circuits of mind and consciousness. The earlier technology of measuring brain chemicals like serotonin or norepinephrine had enabled scientists to look at what fueled neural activity, which is a bit like trying to understand a car's engine by studying gasoline. Neuroimaging made it possible to see inside the engine. By doing so it has also transformed our understanding of trauma.
Harvard Medical School was and is at the forefront of the neuroscience revolution, and in 1994 a young psychiatrist, Scott Rauch, was appointed as the first director of the Massachusetts General Hospital Neuroimaging Laboratory. After considering the most relevant questions that this new technology could answer and reading some articles I had written, Scott asked me whether I thought we could study what happens in the brains of people who have flashbacks.
I had just finished a study on how trauma is remembered (to be discussed in chapter 12), in which participants repeatedly told me how upsetting it was to be suddenly hijacked by images, feelings, and sounds

from the past. When several said they wished they knew what trick their brains were playing on them during these flashbacks, I asked eight of them if they would be willing to return to the clinic and lie still inside a scanner (an entirely new experience that I described in detail) while we re-created a scene from the painful events that haunted them. To my surprise, all eight agreed, many of them expressing their hope that what we learned from their suffering could help other people.

My research assistant, Rita Fisler, who was working with us prior to entering Harvard Medical School, sat down with every participant and carefully constructed a script that re-created their trauma moment to moment. We deliberately tried to collect just isolated fragments of their experience—particular images, sounds, and feelings—rather than the entire story, because that is how trauma is experienced. Rita also asked the participants to describe a scene where they felt safe and in control. One person described her morning routine; another, sitting on the porch of a farmhouse in Vermont overlooking the hills. We would use this script for a second scan, to provide a baseline measurement.

After the participants checked the scripts for accuracy (reading silently, which is less overwhelming than hearing or speaking), Rita made a voice recording that would be played back to them while they were in the scanner.

A typical script:

You are six years old and getting ready for bed. You hear your mother and father yelling at each other. You are frightened and your stomach is in a knot. You and your younger brother and sister are huddled at the top of the stairs. You look over the banister and see your father holding your mother's arms while she struggles to free herself. Your mother is crying, spitting and hissing like an animal. Your face is flushed and you feel hot all over. When your mother frees herself, she runs to the dining room and breaks a very expensive Chinese vase. You yell at your parents to stop, but they ignore you. Your mom runs upstairs and you hear her breaking the TV. Your little brother and sister try to get her to hide in the closet. Your heart pounds and you are trembling.

At this first session we explained the purpose of the radioactive oxygen the participants would be breathing: As any part of the brain became more or less metabolically active, its rate of oxygen consumption would immediately change, which would be picked up by the scanner. We would monitor their blood pressure and heart rate throughout the procedure, so that these physiological signs could be compared with brain activity.

Several days later the participants came to the imaging lab. Marsha, a forty-year-old schoolteacher from a suburb outside of Boston, was the first volunteer to be scanned. Her script took her back to the day, thirteen years earlier, when she picked up her five-year-old daughter, Melissa, from day camp. As they drove off, Marsha heard a persistent beeping, indicating that Melissa's seatbelt was not properly fastened. When Marsha reached over to adjust the belt, she ran a red light. Another car smashed into hers from the right, instantly killing her daughter. In the ambulance on the way to the emergency room, the seven-month-old fetus Marsha was carrying also died.

Overnight Marsha had changed from a cheerful woman who was the life of the party into a haunted and depressed person filled with self-blame. She moved from classroom teaching into school administration, because working directly with children had become intolerable—as for many parents who have lost children, their happy laughter had become a powerful trigger. Even hiding behind her paperwork she could barely make it through the day. In a futile attempt to keep her feelings at bay, she coped by working day and night.

I was standing outside the scanner as Marsha underwent the procedure and could follow her physiological reactions on a monitor. The moment we turned on the tape recorder, her heart started to race, and her blood pressure jumped. Simply hearing the script similar activated the same physiological responses that had occurred during the accident thirteen years earlier. After the recorded script concluded and Marsha's heart rate and blood pressure returned to normal, we played her second script: getting out of bed and brushing her teeth. This time her heart rate and blood pressure did not change.

As she emerged from the scanner, Marsha looked defeated, drawn out, and frozen. Her breathing was shallow, her eyes were opened wide, and her shoulders were hunched—the very image of vulnerability and defenselessness. We tried to comfort her, but I wondered if whatever we discovered would be worth the price of her distress.

Picturing the brain on trauma. Bright spots in (A) the limbic brain, and (B) the visual cortex, show heightened activation. In drawing (C) the brain's speech center shows markedly decreased activation.

After all eight participants completed the procedure, Scott Rauch went to work with his mathematicians and statisticians to create composite images that compared the arousal created by a flashback with the brain in neutral. After a few weeks he sent me the results, which you see above. I taped the scans up on the refrigerator in my kitchen, and for the next few months I stared at them every evening. It occurred to me that this was how early astronomers must have felt when they peered through a telescope at a new constellation.

There were some puzzling dots and colors on the scan, but the biggest area of brain activation—a large red spot in the right lower center of the brain, which is the limbic area, or emotional brain—came as no surprise. It was already well known that intense emotions activate the limbic system, in particular an area within it called the amygdala. We depend on the amygdala to warn us of impending danger and to activate the body's stress response. Our study clearly showed that when traumatized people are presented with images, sounds, or thoughts related to their particular experience, the amygdala reacts with alarm—even, as in Marsha's case, thirteen years after the event. Activation of this fear center triggers the cascade of stress hormones and nerve impulses that drive up blood pressure, heart rate, and oxygen intake—preparing the body for fight or flight.1 The monitors attached to Marsha's arms recorded this physiological state of frantic arousal, even though she never totally lost track of the fact that she was resting quietly in the scanner.

SPEECHLESS HORROR

Our most surprising finding was a white spot in the left frontal lobe of the cortex, in a region called Broca's area. In this case the change in color meant that there was a significant decrease in that part of the brain. Broca's area is one of the speech centers of the brain, which is often affected in stroke patients when the blood supply to that region is cut off. Without a functioning Broca's area, you cannot put your thoughts and feelings into words. Our scans showed that Broca's area went offline whenever a flashback was triggered. In other words, we had visual proof that the effects of trauma are not necessarily different from—and can overlap with—the effects of physical lesions like strokes.

All trauma is preverbal. Shakespeare captures this state of speechless terror in Macbeth, after the murdered king's body is discovered: "Oh horror! horror! horror! Tongue nor heart cannot conceive nor name thee! Confusion now hath made his masterpiece!" Under extreme conditions people may scream obscenities, call for their mothers, howl in terror, or simply shut down. Victims of assaults and accidents sit mute and frozen in emergency rooms; traumatized children "lose their tongues" and refuse to speak. Photographs of combat soldiers show hollow-eyed men staring mutely into a void.

Even years later traumatized people often have enormous difficulty telling other people what has happened to them. Their bodies reexperience terror, rage, and helplessness, as well as the impulse to fight or flee, but these feelings are almost impossible to articulate. Trauma by nature drives us to the edge of comprehension, cutting us off from language based on common experience or an imaginable past.

This doesn't mean that people can't talk about a tragedy that has befallen them. Sooner or later most survivors, like the veterans in chapter 1, come up with what many of them call their "cover story" that offers some explanation for their symptoms and behavior for public consumption. These stories, however, rarely capture the inner truth of the experience. It is enormously difficult to organize one's traumatic experiences into a coherent account—a narrative with a beginning, a middle, and an end. Even a seasoned reporter like the famed CBS correspondent Ed Murrow struggled to convey the atrocities he saw when the Nazi concentration camp Buchenwald was liberated in 1945: "I pray you believe what I have said. I reported what I saw and heard, but only part of it. For most of it I have no words."

When words fail, haunting images capture the experience and return as nightmares and flashbacks. In contrast to the deactivation of Broca's area, another region, Brodmann's area 19, lit up in our participants. This is a region in the visual cortex that registers images when they first enter the brain. We were surprised to see brain activation in this area so long after the original experience of the trauma. Under ordinary conditions raw images registered in area 19 are rapidly diffused to other brain areas that interpret the meaning of what has been seen. Once again, we were witnessing a brain region rekindled as if the trauma were actually occurring.

As we will see in chapter 12, which discusses memory, other unprocessed sense fragments of trauma, like sounds and smells and physical sensations, are also registered separately from the story itself. Similar sensations often trigger a flashback that brings them back into consciousness, apparently unmodified by the passage of time.

SHIFTING TO ONE SIDE OF THE BRAIN

The scans also revealed that during flashbacks, our subjects' brains lit up only on the right side. Today there's a huge body of scientific and popular literature about the difference between the right and left brains. Back in the early nineties I had heard that some people had begun to divide the world between left-brainers (rational, logical people) and right-brainers (the intuitive, artistic ones), but I hadn't paid much attention to this idea. However, our scans clearly showed that images of past trauma activate the right hemisphere of the brain and deactivate the left.

We now know that the two halves of the brain do speak different languages. The right is intuitive, emotional, visual, spatial, and tactual, and the left is linguistic, sequential, and analytical. While the left half of the brain does all the talking, the right half of the brain carries the music of experience. It communicates through facial expressions and body language and by making the sounds of love and sorrow: by singing, swearing, crying, dancing, or mimicking. The right brain is the first to develop in the womb, and it carries the nonverbal communication between mothers and infants.

We know the left hemisphere has come online when children start to understand language and learn how to speak. This enables them to name things, compare them, understand their interrelations, and begin to communicate their own unique, subjective experiences to others.

The left and right sides of the brain also process the imprints of the past in dramatically different ways.2 The left brain remembers facts, statistics, and the vocabulary of events. We call on it to explain our experiences and put them in order. The right brain stores memories of sound, touch, smell, and the emotions they evoke. It reacts automatically to voices, facial features, and gestures and places experienced in the past. What it recalls feels like intuitive truth—the way things are. Even as we enumerate a loved one's virtues to a friend, our feelings may be more deeply stirred by how her face recalls the aunt we loved at age four.3

Under ordinary circumstances the two sides of the brain work together more or less smoothly, even in people who might be said to favor one side over the other. However, having one side or the other shut down, even temporarily, or having one side cut off entirely (as sometimes happened in early brain surgery) is disabling.

Deactivation of the left hemisphere has a direct impact on the capacity to organize experience into logical sequences and to translate our shifting feelings and perceptions into words. (Broca's area, which blacks out during flashbacks, is on the left side.) Without sequencing we can't identify cause and effect, grasp the long-term effects of our actions, or create coherent plans for the future. People who are very upset sometimes say they are "losing their minds." In technical terms they are experiencing the loss of executive functioning.

When something reminds traumatized people of the past, their right brain reacts as if the traumatic event were happening in the present. But because their left brain is not working very well, they may not be aware that they are reexperiencing and reenacting the past—they are just furious, terrified, enraged, ashamed, or frozen. After the emotional storm passes, they may look for something or somebody to blame for it. They behaved the way they did way because you were ten minutes late, or because you burned the potatoes, or because you "never listen to me." Of course, most of us have done this from time to time, but when we cool down, we hopefully can admit our mistake. Trauma interferes with this kind of awareness, and, over time, our research demonstrated why.

STUCK IN FIGHT OR FLIGHT

What had happened to Marsha in the scanner gradually started to make sense. Thirteen years after her tragedy we had activated the sensations—the sounds and images from the accident—that were still stored in her memory. When these sensations came to the surface, they activated her alarm system, which caused her to react as if she were back in the hospital being told that her daughter had died. The passage of thirteen years was erased. Her sharply increased heart rate and blood pressure readings reflected her physiological state of frantic alarm.

Adrenaline is one of the hormones that are critical to help us fight back or flee in the face of danger. Increased adrenaline was responsible for our participants' dramatic rise in heart rate and blood pressure while listening to their trauma narrative. Under normal conditions people react to a threat with a temporary increase in their stress hormones. As soon as the threat is over, the hormones dissipate and the body returns to normal. The stress hormones of traumatized people, in contrast, take much longer to return to baseline and spike quickly and disproportionately in response to mildly stressful stimuli. The insidious effects of constantly elevated stress hormones include memory and attention problems, irritability, and sleep disorders. They also contribute to many long-term health issues, depending on which body system is most vulnerable in a particular individual.

We now know that there is another possible response to threat, which our scans aren't yet capable of measuring. Some people simply go into denial: Their bodies register the threat, but their conscious minds go on as if nothing has happened. However, even though the mind may learn to ignore the messages from the emotional brain, the alarm signals don't stop. The emotional brain keeps working, and stress hormones keep sending signals to the muscles to tense for action or immobilize in collapse. The physical effects on the organs go on unabated until they demand notice when they are expressed as illness. Medications, drugs, and alcohol can also temporarily dull or obliterate unbearable sensations and feelings. But the body continues to keep the score.

We can interpret what happened to Marsha in the scanner from several different perspectives, each of which has implications for treatment. We can focus on the neurochemical and physiological disruptions that were so evident and make a case that she is suffering from a biochemical imbalance that is reactivated whenever she is reminded of her daughter's death. We might then search for a drug or a combination of drugs that would damp down the reaction or, in the best case, restore her chemical equilibrium. Based on the results of our scans, some of my colleagues at MGH began investigating drugs that might make people less responsive to the effects of elevated adrenaline.