PART ONE

AN OVERVIEW OF THE BRAIN

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HOW OUR BRAIN CONSTRUCTS OUR MENTAL WORLD

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Von Hemholtz's Darkroom Experiment

Look up from this book and focus your attention for a few seconds on the first thing that meets your eye. Then return to the book. When you looked up, you didn't have any problem understanding what I meant by attention, did you? One moment you were engaged in reading a sentence, and the next moment you had shifted your attention and you were looking at . . . whatever. It was as if you had directed the beam of a flashlight from one portion of a darkened room to another. Yet attentional shifts don't necessarily involve eye movements. You could just as easily have shifted your attention by simply thinking of something you had to do later today. But what is it exactly that you would be shifting at such a time? This question tantalized the eminent nineteenth-century German scientist Hermann von Helmholtz, who carried out an experiment on attention.

Helmholtz was intrigued with the question of how much information a person could process in a brief period of time. To find out, he used a flashbulb to briefly illuminate an otherwise dark scene consisting of letters painted onto a sheet suspended at one end of his lab. When Helmholtz triggered the flash of light in the dark it provided a short-lived illumination of the letters. He immediately discovered that he couldn't take in all of the letters during the brief illumination; he could see only some of them. But if he decided ahead of time which portion of the screen he would attend to during the illumination, he could easily discern those letters despite his continued inability to perceive letters elsewhere on the screen.

Helmholtz was paying what psychologists now refer to as *covert visual attention* to a chosen region of the sheet of letters: "By a voluntary kind of intention, even without eye movements, . . . one can concentrate attention on the sensation from a particular part and at the same time exclude attention from all other parts."

Today neuroscientists can illustrate what's going on in the brain during Helmholtz's ingenious experiment. When you focus your visual attention on something in your immediate surroundings, the blood flow immediately increases in the visual areas of your brain. But this increase in activity isn't just a generalized increase; it occurs in a highly specific pattern. If you attend to something off to your left, your brain's right visual area is activated; if you attend to something off to your right, it's the left visual area that comes alive. (Remember that the visual hemispheres on the two sides of the brain scan the opposite visual fields.)

Think for a moment what such findings imply. As you direct your visual attention to something in your surroundings, your brain has already begun—thanks to your intention to look at one thing rather than another—to selectively focus on that one aspect of the world in front of you. Thus, in the words of George R. Mangun of the Center for Mind and Brain, University of California, Davis, "Changes in visual brain processing significantly affect how we perceive and respond to the world around us."

Magicians have known about this intention-attention link for centuries and take advantage of it via the technique of misdirection. If a trick "works," it's often because the magician has successfully fooled his audience into purposely (intentionally) focusing their attention on an unimportant aspect of the trick, thus preventing them from seeing what he's actually doing.

Thinking Is for Doing

Not only intention and attention but all other states of mind and body are related to and oftentimes determined by our brain. As an example of my point, say the word *zeal* out loud. Now without changing the position of your lips and mouth in any way, simply imagine saying it. Hold that imagined feeling. Now open your mouth as wide as you can and imagine once again saying *zeal*. Feels quite different, doesn't it?

This simple exercise underscores an important point: Our mental processes are sufficiently tethered to our bodily senses that we have difficulty with situations when the brain and other parts of the body aren't in sync. You'll experience difficulty in any mental activity when your body executes movements that thwart it: it's hard to think critically while slumped in an armchair, hard to meditate on compassion while punching a bag.

Here's another example. Clench your fists, hard, and grit your teeth. At the same time imagine yourself pushing a heavy piece of furniture across the living room. Then quickly change the thought to lying on a beach in the Caribbean listening to gentle waves. Notice how much harder it is to maintain that thought with those clenched fists and that tightened jaw? Now unclench your fists and loosen your jaw and return to the image of pushing that furniture. That doesn't feel quite right either: We don't push furniture with hands and jaw relaxed.

Next, sit for a few moments with your forearm flexed as if you're about to pull something toward you. Now imagine me showing you a series of items or speaking a series of words and then asking you how you feel about them. I then ask you to repeat the exercise with your arm held straight out in a fully extended position. Would it surprise you—as it did me—to learn that you'll tend to like the various items you encountered while holding your arm in the flexed position, and dislike the items heard while your arm is extended? That's what was found in a test measuring the association of arm posture and attitude.

Flexing the arm, of course, is a motion we all carry out when we're pulling something toward us, "embracing" it; straightening the arm, or "strong-arming," in contrast, is what we do when we want to push something away. For those requiring more convincing evidence of the connection between our personal evaluations and our bodily positions, the experimenters repeated the experiment, but this time with a twist: half of the participants in the experiment were asked to push a lever away from them if they reacted positively to a particular word but pull it toward them if the word gave rise to negative associations, while the other half of the participants were told to do the opposite, pulling forward with positive words and pushing away with negative words. Overall, people were faster to respond to positive words when they were pulling instead of pushing the lever, and faster to respond to negative words when they were pushing rather than pulling the lever.

The experimenters tried the experiment again, only this time they didn't say anything about likes or dislikes. Half the volunteers simply responded by pushing the lever as quickly as possible whenever a word appeared; the other half of the participants in this reaction time experiment pulled the lever at the instant they became aware of the word. Again, those pushing the lever reacted more quickly to negative words, while the lever pullers responded faster to positive words.

"Immediately and unintentionally a perceived object or event is classified as either good or bad, and this results, in a matter of milliseconds, in a behavioral predisposition toward that object or event," according to Yale University psychologist John Bargh, who carried out the research just described.

Think for a moment about the usefulness of such an arrangement. Thanks to these automatic responses, it's not necessary to consciously evaluate everything that's happening from moment to moment. Rather, our bodily movements automatically bring us closer to positive events and experiences but increase the distance between negative ones and us. This is especially helpful when our conscious mind is otherwise engaged in thinking about other matters, such as our presentation at tomorrow's weekly staff meeting.

This intimate association between body and thought intrigued the nineteenth-century psychologist William James, who emphasized the intimate association that exists between thinking and action. In 1890 James wrote, "It is a general principle of psychology that consciousness deserts all processes where it can no longer be of use. . . . We grow unconscious of every feeling which is useless as a sign to lead us to our ends." Unlike his brother, the novelist Henry James, William James favored tightly compressed aphorisms over lengthy and baroque paragraphs: "Thinking is for doing," he wrote. These four words simplify without oversimplifying the notion that merely thinking about doing something increases the likelihood that one will actually do it. While this seems a fairly commonsense notion—most of us can readily bring personal examples to mind—James developed it a good bit further. Indeed, he took the notion quite literally and argued for the then-maverick view that thinking about doing something activates the same brain regions that come into play when one actually does it.

A hundred years later PET [positron emission tomography] scan studies confirm James's proposal. Starting in the early 1990s, neuroscientists provided PET scan evidence that thinking about a word or about carrying out a movement activates the same area in the anterior cingulate that is activated when actually saying the word or carrying out the movement.

"These studies support the notion that thinking about something and doing it are neurologically similar. And the two activities activate the same regions of the brain, suggesting they share representational systems," says Duke University psychologist Tanya L. Chartrand, an expert on the link between thinking and doing.

Chartrand's comment is important because it's in line with the advice of psychotherapists and motivational experts who suggest imaginational exercises as the first step toward self-improvement. They advise envisioning yourself as the person you want to become, or changing a situation that's troubling you by imagining that change as a prelude to making it happen.

Mirror Neurons

Although we like to think of ourselves as independent and self-actualizing, our thoughts and behavior are powerfully influenced by other people's actions. This holds true even at the level of simple observation. When we watch another person move, our observation of the movement activates those areas in our brain that we would use if we moved the same way. This was first discovered in macaque monkeys, where "mirror neurons" in the prefrontal cortex respond both when the monkey grasps a peanut and when it watches another monkey grasp it. Even hearing sounds suggestive of a monkey grasping and then breaking a peanut activates the mirror neurons. This suggests that the mirror neurons for vision and hearing aren't just coding movements and sounds but rather goals and meanings: What is the monkey doing? Further, mirror neurons can be trained. If a monkey is taught to rip paper or perform some other action that doesn't come naturally to the animal, specific mirror neurons will start to fire at the mere sound of ripping paper.

A similar perception-action matching system exists in the human brain. Imagine yourself watching me reach out and grasp the cup of tea that now sits on the small table next to my word processor. As you observe my hand reaching for the cup, the motor cortex in your brain will also become slightly active in the same areas you would use if you reached out to pick up that teacup. Further, if you watch my lips as I savor the tea, the area of your brain corresponding to lip movements will activate as well.

No, that doesn't mean you can taste my tea. But it does mean that I'm directly affecting your brain as you watch me go through the motions of drinking my tea. In such a situation the neat division between you and me breaks down and we form a unit in which each of us is influencing the other's actions at the most basic level imaginable: I am altering your brain as a result of your observations of me, and vice versa.

Notice that it isn't necessary for you to consciously think about the movement in order to get your brain working. Merely observing me move my hand toward the teacup will activate those portions of your brain that would come into play if you actually moved your hand. But if I move my hand toward the teacup for a purpose other than sipping tea, the mirror neurons fail to fire. We know this because of a clever experiment carried out by a team led by Marco Iacoboni of the University of California, Los Angeles.

In this test of mirror neuron responses, volunteers watched video clips taken before and after a tea party. The "before" clip showed a steaming teapot and cup placed alongside a neatly arranged plate of cookies. The "after" clip depicted an empty teapot, scattered cookie crumbs, and a used napkin. At the conclusion of both video clips a hand reached in from off-camera and grasped the teacup. Since the hand motion was identical in each clip, only the context suggested two different intentions: drinking the tea in the "before" clip versus tidying up in the "after" clip.

As fMRI [functional magnetic resonance imaging] scans of the volunteers' brains showed, brain activity in these two situations differed markedly. The greatest activity in the right frontal cortex (known from previous research to process mirrorlike responses to hand movements) occurred while the volunteer watched the grasping movement associated with drinking the tea. Thus mirror neurons are affected not just by motion but also by the motivation behind it, according to Iacoboni.

Think for a moment of the implications of this. You can activate my brain if you can attract my attention enough to get me to watch what you're doing, and vice versa. Thanks to the mirror neurons in each of our brains, a functional link exists between my brain and yours.

Nor does any actual movement have to take place in order for this mutual influence of one brain on another to take place. For instance, imagine someone reading to you the following list of words: *plain, rip, geography, stomp, Ireland, wistful, lift*. If you are listening to the words while in a PET scan, the action verbs *rip, stomp*, and *lift* will activate areas of the brain normally engaged if you were actually ripping, stomping, or lifting. Called into play would be the dorsolateral prefrontal cortex, the anterior cingulate, and the premotor and parietal cortices. The same thing would happen if you were watching someone else rip, stomp, and lift, if you spoke the words aloud, or if you dredged up those words from memory.

Valeria Gazzola of the BCN Neuroimaging Center in Gröningen, the Netherlands, has spun the mirror neuron concept in a more intimate direction. In her experiments on auditory empathy she discovered that when a person listens to a sound associated with an action such as kissing, the act of listening activates the same area in the premotor cortex that would come online if that person actually kissed someone: the kissing sounds activated areas of the premotor cortex controlling the mouth movements associated with kissing. Certainly Gazzola's findings are in sync with our everyday experience. As Gazzola puts it: "If in a hotel room, we hear the neighbor's bed squeaking rhythmically, we can't help hearing more than just a sound."

Part of that intuition comes from the capacity of mirror neurons to distinguish between biological and nonbiological actions. Beds don't move on their own and, with one notable exception, usually don't squeak rhythmically. Monkeys make a similar distinction when another monkey is involved in an action compared to a machine carrying out that action. It will grasp something when it sees another monkey do it, but remains unmoved when pliers or a mechanical tool performs the same action. Human infants show a pattern much like this. At eighteen months an infant will imitate and even complete an action made by a human but will fail to imitate a robot making the same movement. This also holds true for sounds. Infants older than nine months can learn new speech sounds to which they have never been exposed, but only if the new sounds come from a real person. Learning the new sound doesn't occur at this age if the infant hears the same word on a tape recorder or video.

In adults, speaking action words activates the same brain structures as actually carrying out the actions (the verb-behavior link, as neuropsychologists refer to it). That linkage is one of the reasons we become annoyed when someone asks us a question while we're trying to concentrate. The question automatically activates those parts of our brain involved in formulating the answer to that question. We're annoyed because of the conscious effort we must exert not to become distracted—that is, direct our attention away from our current thoughts in order to formulate a response to the question. In such situations we learn firsthand that although our brain can carry out many processes simultaneously, the focus of our conscious attention is limited to a few things at a time.

Mental imagery is actually an offshoot of our capacity for activating those mirror neurons. Think for a moment about a pleasant experience you had, say, during your last vacation. I'm thinking at the moment of the view of the beach from the patio of my hotel room at Maui in Hawaii. Although I can "see" the scene very clearly in my imagination, the experience obviously isn't the same as actually being there. From the point of view of physical location, thousands of miles separate the two experiences. But what about the representation of these two experiences in my brain? How does my creation of a mental image within my brain differ from the original experience? Actually, not nearly as much as you might expect.

Over the last decade neuroscientists have discovered that the visual imagery employed in an imaginative re-creation of an earlier experience shares important features with the original visual perception. As I think about the beach many of the same areas will be activated in my brain that were active when I was physically there. And the time that it took me to scan the view of the beach from my patio is equal to the time it takes me now to mentally imagine the same scene. Moreover, if you ask me a question about the beach, my brain will direct my eyes to look downward, just as it would if I were once again looking down from the patio. A question about how the beach appeared from the right of the patio will provoke an unconscious shift of my eyes to the right (or to the left if you asked about how the beach appeared from that direction).

Thanks to mirror neurons, we can mentally rehearse physical activities without actually doing them. If you've learned a physical exercise and then later mentally rehearse it, you will induce an increase in muscle strength comparable to what would happen if you actually did the exercise. What's more, your heart rate and breathing frequency will increase linearly with the increase in the imagined effort: the greater the exertion you imagine yourself making, the more your heart and breathing rates will increase. If you are put into an fMRI scan, many of the same areas will activate as when you actually did the exercise (the primary motor cortex, the premotor cortex, the SMA [supplementary motor area], the basal ganglia, and the cerebellum).

Not everyone shows the same degree of mirroring. When observing someone playing the piano, skilled pianists show stronger motor activation than the musically naive. But if they watch random finger movements instead, the brain responses of the pianists are indistinguishable from people with no special musical expertise or interest. A similar situation exists among dancers. In an ingenious study Bentriz Calvo-Merino of the Institute of Movement Neuroscience, University College London, compared the brain activation patterns of ballet dancers and capoeira dancers (capoeira is an Afro-Brazilian martial dance first developed by slaves in Brazil more than four hundred years ago as a means of fighting back against the slave owners). She found greater brain activation when the dancers viewed movements they had been trained to perform compared to movements they had not. That is, the ballet dancers showed stronger brain activation while observing ballet movements than when observing capoeira movements, and among capoeira dancers, the greater activation occurred while watching capoeira.

In response to this demonstration of the power of imagery for elaborate movement sequences, coaches and trainers have incorporated various imaging exercises into athletic and physical fitness training programs. Obviously, this reliance on imaging can only go so far. That's why the world is still waiting (and will continue to wait, I expect) for the first winner at Wimbledon whose training has consisted only of mental exercises. While thinking and doing activate the same brain areas, the winning of a tennis game, as any regular player knows quite well, requires physical and not just mental effort.

So think about those mirror neurons the next time someone talks to you about the power of human imagination. Imagination involves the activation of sensory and action centers in the brain. Not only can we now locate it within specific areas of the brain, but we can also quantify it. And for the most part imagination is a power that we control: We consciously invoke the images in our imagination or, on those occasions when an image spontaneously springs to mind, we can consciously suppress it. Further, we can "build up" our imaginative powers just as we do our muscular strength.