The Mind and the Brain: Neuroplasticity and the Power of Mental Force - Jeffrey M. Schwartz, Sharon Begley (2003)

Chapter 10. ATTENTION MUST BE PAID

The task is…not so much to see what no one has yet seen; but to think what nobody has yet thought, about that which everybody sees.

—*Erwin Schrödinger*

On Christmas Eve day 1999, I flew up to San Francisco, taking advantage of a seventy-nine-dollar round-trip fare so that I could touch base with Henry Stapp. Henry picked me up at the airport, and after lunch at a trattoria in North Beach we drove across the bridge to Berkeley. I had recently been rereading William James's work on attention, I told Henry, and realized how uncannily the perspective of this nineteenth-century psychologist foreshadowed the work Henry was doing. I hadn't taken my copy of James's *Psychology: A Briefer Course* with me, so Henry and I set out to find one.

After parking near Telegraph Avenue, we walked past street people slumped against doorways and sprawled across sidewalks, the gaiety of stores' Christmas decorations forming an incongruous backdrop. We ducked into Cody's bookstore and split up, looking for James everywhere from self-help to religion. No luck. But at Moe's used bookstore down the block, we hit paydirt. There in the psychology section, amid what seemed like oceans of Jung, was a single slim volume of James. I opened it to this passage:

I have spoken as if our attention were wholly determined by neural conditions. I believe that the array of things *we can attend to is so determined. No object can* catch *our attention except by the neural machinery. But the*amount *of the attention which an object receives after it has caught our mental eye is another question. It often takes effort to keep the mind upon it. We feel that we can make more or less of the effort as we choose. If this feeling be not deceptive, if our effort be a spiritual force, then of course it contributes coequally with the cerebral conditions to the result. Though it* introduce *no new idea, it will deepen and prolong the stay in consciousness of innumerable ideas which else would fade more quickly away…. [I]t is often a matter of but a second more or less of attention at the outset, whether one system shall gain force to occupy the field and develop itself, and exclude the other, or be excluded itself by the other…. [T]he whole drama of the voluntary life hinges on the amount of attention, slightly more or slightly less, which rival motor ideas may receive…. Effort may be an original force and not a mere effect, and it may be indeterminate in amount*.

As we stood at the counter paying for our find, I could tell by the change in Henry's usually impassive demeanor that I had piqued his interest. "See—I told you it was uncanny how relevant James was to the physics of attention!" I said. Even the guy behind the cash register seemed interested.

Walking down the street to Henry's car, I continued reading aloud. (This was Berkeley on Christmas Eve: no one looked twice at us.) But there was more, I told Henry. Riffling through the book, I opened it to a passage several chapters later: "Volitional effort is effort of attention." And this: "The function of the effort is…to keep affirming and adopting a thought which, if left to itself, would slip away." And, "Effort of attention is thus the essential phenomenon of will." And finally, "To sustain a representation, to think, is, in short, the only moral act." Here we got to the nub of it, the conviction that the act of focusing attention so that one thought, one possible action, prevails over all the other possible ones competing for dominance in consciousness—this is the true moral act, the point where volition enters into what James had just called "the cerebral conditions" and, moreover, "contribute[s] coequally" to them in determining which of those competing thoughts and actions will be chosen. It is this power of attention—to select one possibility over all others—that invests us with an efficacious will.

"It's uncanny," I repeated. "It's unbelievable," Henry said. A man of the nineteenth century had described in detail the connection between the quantum-based theory of attention and volition that we described in our "Volitional Brain" papers. The causal efficacy of will, James had intuited more than one hundred years ago, is a higher-level manifestation of the causal efficacy of attention. To focus attention on one idea, on one possible course of action among the many bubbling up inchoate in our consciousness, is precisely what we mean by an act of volition, James was saying; volition acts through attention, which magnifies, stabilizes, clarifies, and otherwise makes predominant one thought out of many. The essential achievement of the will is to attend to one object and hold it clear and strong before the mind, letting all others—its rivals for attention and subsequent action—fade away like starlight swamped by the radiance of the Sun. That was just the idea that had emerged from the quantum approach. I handed the book to Henry and said, "Merry Christmas, and happy New Millennium."

Once settled in Henry's car, we drove back across the Bay Bridge, talking animatedly about how James had come to a scientific understanding of the origin and efficacy of volition that was exactly in line with what quantum theory was telling us a century later. We were just picking up where James left off, I felt; it was as if we'd encountered a time warp that bypassed the entire twentieth century and took us directly from the late nineteenth century to the year 2000.

Given James's strong philosophical bent, it's hardly surprising these twin concepts, attention and will, were of such tremendous importance to him. He was well aware, especially given his goal of placing psychology squarely within natural science, that thickets of controversy awaited anyone willing to tackle the question of free will. But on the key point of the causal efficacy of attention, and its relation to will, James held fast to his belief—one he suspected could not be proved conclusively on scientific grounds, but to which he clung tenaciously on ethical grounds—that the effort to focus attention is an active, primary, and causal force, and not solely the result of properties of a stimulus that acts on a passive brain. Between his 1,300-

plus-page *Principles* and the 443-page *Briefer Course* published fifteen months later, he did not budge from (indeed, he elaborated on) the statement that effortful attention "would deepen and prolong the stay in consciousness of innumerable ideas which else would fade more quickly away." If we can but understand the effort of attention, James believed, we will have gone a very long way toward understanding the nature of will.

What particularly struck me was James's recognition of the high stakes involved. The question of whether attention (and therefore will) follows deterministically upon the predictable response of brain cells to stimuli, or whether the amount of attention can be (at least sometimes) freely chosen and causally efficacious, "is in fact the pivotal question of metaphysics, the very hinge on which our picture of the world shall swing from materialism, fatalism, monism, towards spiritualism, freedom, pluralism,—or else the other way." James was scrupulously fair in giving equal time to the view that attention is a fully determined result of brain function rather than a causally efficacious force. As he notes, it is entirely plausible that attention may be "fatally predetermined" by purely material laws. In this view, the amount of attention we pay a stimulus, be it one from the world outside or an internally generated thought or image, is determined solely by the properties of that stimulus and their interaction with our brain's circuits. If the words you hear or the images you see are associated with a poignant memory, for instance, then they trigger—automatically and without any active effort by you—more attention than stimuli that lack such associations. In this case, "attention only fixes and retains what the ordinary laws of association bring 'before the footlights' of consciousness," as James put it. That is, the stimuli themselves provoke neural mechanisms that cause them to be attended to and fixed on. This is the attention-as-effect school of thinking.

But James did not think that attention was always and only a fully determined effect of the stimuli that are its object. On the flight back to Los Angeles, I went over in my own mind what we knew about attention, and why it mattered.

We go through our lives "seeing" countless objects that we do not pay attention to. Without attention, the image (or the sound, or the feel—attention plays a role in every sense) does not register in the mind and may not be stored even briefly in memory. I can guarantee that if you were to scan every square centimeter of a crowd scene in a photograph, visual information about every person depicted would reach your visual cortex. But if I asked you, after you had scanned the photo of the crowd, where the man in the fedora and vest was, you would doubtless be flummoxed. Our minds have a limited ability to process information about multiple objects at any given time. "Because of limited processing resources," as the neuroscientists Sabine Kastner and Leslie Ungerleider of NIH wrote in a 2000 review of attention, "multiple objects present at the same time in the visual field compete for neural representation…. Two stimuli present at the same time within a neuron's receptive field are not processed independently. [R]ather,…they interact with each other in a mutually suppressive way." They compete for neural representation. The key question for attention is, What determines the winner?

Let's say I asked you, before you looked at the picture, to find the man in fedora and vest. With your mind thus primed, you would probably find him in seconds. You would have selected the relevant stimulus and filtered out the extraneous ones. How? According to our best understanding, the images of scores of people (to continue with our example of the crowd photo) sped from your retina and into your visual cortex, in parallel. But then competition set in. The winner was determined by the strength of the stimulus (perhaps the man in the fedora is brighter than the other images), by its novelty (we tend to pick out, say, the tuxedoed monkey at a black-tie dinner before we notice the humans), by its strong associations (if you scan a crowd scene for someone you know, you can generally pick her out before a stranger), or, most interestingly, by the demand of the task—in this case, looking for "the man in fedora and vest." Selectively focusing attention on target images significantly enhances neuronal responses to them.

This is especially true when nearby stimuli, if not for the power of attention, would distract us. In general, when two images are presented simultaneously, each suppresses the neuronal activity that the other triggers. But selective focusing of attention can override this effect and thereby filter out distractions. How do we know? When physiologists record electrical activity in the brains of monkeys doing tasks that require selective attention, they find that the firing of neurons activated by a target image becomes significantly enhanced when the monkeys selectively focus attention on it, effectively eliminating the suppressive influence of nearby images. Human brains act the same way, according to functional magnetic resonance imaging (fMRI) : neurons that respond to a target (the image attracting your attention) fire more strongly than neurons that respond to a distraction. The act of paying attention, then, physically counteracts the suppressive influences of nearby distractions. Robert Desimone of the National Institute of Mental Health, one of the country's leading researchers into the physiology of attention, explains it this way: "Attention seems to work by biasing the brain circuit for the important stimuli. When you attend to a stimulus, the suppression that distracters otherwise cause is reduced."

In other words, selective attention can strengthen or weaken neural processing in the visual cortex. This seems to happen in at least two ways. In the first, the neural response to the object of attention becomes stronger. In one fascinating series of experiments, monkeys were trained to look for the color of an object that flashed on a screen. When they did, neurons that respond to color became more active. Similarly, when the monkeys were trained to keep an eagle eye on the direction an object was moving, or on its orientation, neurons that perform those tasks became more active. Attention to shape and color pumps up the volume of neuronal activity in the region of the visual cortex that processes information about shape and color; attention to speed turns up the activity of neurons in the region that processes information about speed. In people, paying attention to faces turns up activity in the region whose job it is to scan and analyze faces.

If this seems somewhat self-evident, it's worth another look: the visual information reaching the brain hasn't changed. What has changed—what is under the observer's control—is the brain's response to that information. Just as visual information about the color of this book's cover reached your brain as you opened it, so every aspect of the objects on the screen (their shape, color, movements, etc.) reached the monkey's brain. The aspect of the image that monkey pays attention to determines the way its brain responds. Hard-wired mechanisms in different brain areas get activated, or not, depending on what the monkey is interested in observing. An activity usually deemed to be a property of the mind—paying attention—determines the activity of the brain.

Attention can do more than enhance the responses of selected neurons. It can also turn down the volume in competing regions. Ordinarily—that is, in the absence of attention—distractions suppress the processing of a target stimulus (which is why it's tough to concentrate on a difficult bit of prose when people are screaming on the other side of a thin wall). It's all well and good for a bunch of neurons to take in sounds at a boisterous party, but you can't make out a damn thing until you pay attention. Paying attention to one conversation can suppress the distracting ones. Neurons that used to vibrate with the noise of those other conversations are literally damped down and no longer suppress the response of neurons trying to hear the conversation you're interested in. Anyone who has ever had the bad luck to search for a dropped contact lens has also had the experience of paying attention to one object (the lens) and thus suppressing neuronal responses to other objects (bits of lint in a rug). If you are searching for a contact lens on a Persian rug, you can thank this effect for hushing the neurons that respond to those flowers and colors, and turning up the responses of neurons that respond to the glimmer of light reflecting off little clear disks. Specifically, it is the activity of neurons deep in the brain's visual pathway, rather than in the primary visual cortex, that is damped down or turned up by attention.

It often takes real effort to maintain the appropriate focus, which is why it takes so much concentration to get into the proper exit lane at a complicated freeway interchange. But once you muster the appropriate focus, you can literally direct your brain to filter out the suppressive effects of distracting signals. Willfully directed attention can filter out unwanted information—another example of how directed mental force, generated by the effort of directed attention, can modulate neuronal function.

When it comes to determining what the brain will process, the mind (through the mechanism of selective attention) is at least as strong as the novelty or relevance of the stimulus itself. In fact, attention can even work its magic in the total absence of sensory stimuli. If an experimenter teaches a monkey to pay attention to a certain quadrant of a video screen, then single-cell recordings find that neurons responsible for that area will fire 30 to 40 percent more often than otherwise, even when there is no there there—even, that is, when that quadrant is empty. So here again we have the mental act of paying attention acting on the activity of brain circuits, in this case turning them up before the appearance of a stimulus. fMRIs find that activity spikes in human brains, too, when volunteers wait expectantly for an object to appear in a portion of a video monitor. Even before an object appears, attention has already stacked the neuronal deck, activating the visual cortex and, even more strongly, the frontal and parietal lobes—the regions of the brain where attention seems to originate. As a result, when the stimulus finally shows up it evokes an even greater response in the visual cortex than if attention had not primed the brain. This, says Robert Desimone (who happens to also be Leslie Ungerleider's husband), "is the most interesting finding. In attention without a visual stimulus, you get activation in the same cells that would respond to that stimulus, as if the cells are primed. You also get activation in the prefrontal cortex and parietal lobes. That seems like strong evidence that these lobes exert top-down control on what the sensory system processes." To summarize, then, selective attention—reflecting willful activation of one circuit over another—can nudge the brain into processing one signal and not another.

Much of what neuroscientists have learned about attention lately has come from brain imaging. As in so many other areas of neurobiology, imaging beckons with the siren call of finding "the neural correlates of…": that is, pinpointing activity in some part of the brain that corresponds to a mental activity. And although I am the last person to equate brain states, or areas of neuronal activity, with attention or any other mental act or experience, it is worth exploring the results of imaging for what they tell us about what is happening in the brain (and where it's taking place) when we pay attention. Briefly, these imaging studies have shown that there is no single attention center in the brain. Rather, there are multiple distributed systems, including those in the prefrontal cortex (involved in task-related memory and planning), parietal cortex (bodily and environmental awareness), and anterior cingulate (motivation). Also activated are the underlying cerebellum and basal ganglia (habit formation and coordination of movement). That's all very nice, but it doesn't really tell us much about how attention works (that's the trouble with the neural-correlates approach). Fortunately some brain imaging studies have gone beyond this, to reveal some truly interesting things about attention.

In 1990, researchers led by Maurizio Corbetta at Washington University went beyond the monkey work to study attention in humans, showing that when you pay attention to something, the part of your brain that processes that something becomes more active. The scientists' subjects watched a computer screen while an array of a dozen identical little boxes appeared for 400 milliseconds. After a 200-millisecond pause, another screen, also filled with geometric shapes, appeared. Half the time, the first and second frames were identical; half the time they differed in one feature or more, such as color or shape or motion of the elements. The volunteers were sometimes told to determine whether the two succeeding images differed at all, and sometimes told to determine whether the images differed specifically in color, in shape, or in motion. Looking for any old difference is an example of "divided attention," in that subjects have to pay attention to more than a single attribute in their visual field, searching and scanning to find a difference. Focusing on a specific attribute, on the other hand, requires "selective attention."

As you might expect, when the volunteers focused attention on a single attribute ("Are the colors of these objects different from the ones you just saw?"), they did much better at identifying how the second screen differed from the first than when they divided their attention among several attributes ("What's different here?"). But then the study turned up what has become a key finding in the science of attention. Active, focused attention to a specific attribute such as color, they discovered, ramps up the activity of brain regions that process color. In other words, the parts of the brain that process color in an automatic, "hard-wired" way are significantly and specifically activated by the willful act of focusing on color. Activity in brain areas that passively process motion are amplified when volunteers focus attention on motion; areas that passively process shape get ramped up when the volunteers focus on shape. Brain activity in a circuit that is physiologically dedicated to a particular task is markedly amplified by the mental act of focusing attention on the feature that the circuit is hard-wired to process. In addition, during the directing of such selective attention, the prefrontal cortex is activated. As we saw in Chapter 9, this is also the brain region implicated in volition or, as we are seeing, in directing and focusing attention's beam.

The following year, another team of neuroscientists confirmed that attention exerts real, physical effects. This time, they looked not for increased neuronal activity but for something that often goes along with it: blood flow. After all, blood carries oxygen to neurons just as it does to every other cell in the body. Just as a muscle engaged in strenuous aerobic activity is a glutton for oxygen, so a neuron that's firing away needs a voluminous supply of the stuff. In the 1991 experiment, some subjects were instructed to pay attention to vibrations applied to the tips of their fingers, while others were not. The researchers found that, in the subjects paying attention to the vibrations, activation in the somatosensory cortex region representing the fingertips increased 13 percent compared to activation in subjects receiving the identical stimulation but not paying attention. It was another early hint that paying attention to some attribute of the sensed world—colors, movements, shapes, faces, feels, or anything else—affects the regions of the brain that passively process that stimulus. Attention, then, is not some fuzzy, ethereal concept. It acts back on the physical structure and activity of the brain.

Attending to one sense, such as vision, does not simply kick up the activity in the region of the brain in charge of that sense. It also reduces activity in regions responsible for other senses. If you are really concentrating on the little black lines and curves on this white page, you are less likely to feel someone brush against you, or to hear someone speaking in the background. When you watch a ballet, if you're focusing on the choreography, you don't hear the music so well. If you're deep in conversation at a noisy party and your partner in dialogue has a deep baritone voice, it is probable that those parts of your auditory cortex that are tuned to low frequency will get an extra activation boost; at the same time, regions of the auditory cortex that process sopranos are likely turned down, with the result that you may literally not hear (that is, be conscious of) a high-pitched voice across the room. Attention, as the neuroscientist Ian Robertson of Trinity College Dublin says, "can sculpt brain activity by turning up or down the rate at which particular sets of synapses fire. And since we know that firing a set of synapses again and again makes [them] grow…stronger, it follows that attention is an important ingredient" for neuroplasticity, a point we will return to later. For now, it is enough simply to emphasize that paying attention to a particular mode of sensation increases cerebral activity in the brain region that registers that sensation. More generally, the way an individual willfully focuses attention has systematic effects on brain function, amplifying activity in particular brain circuits.

A growing body of evidence demonstrates that mindfulness itself may be a key factor in the activating process. In one fascinating experiment, Dick Passingham of Oxford University and colleagues at London's Institute of Neurology compared the brain activity of a young man as he tried to figure out a mystery sequence on a keypad, to the brain activity after he had mastered it. All the man was told was that he had to figure out which sequence of eight keys was correct. He did it by trial and error: when he pressed an incorrect key, a low-pitched tone sounded, much as hearing a sour note tells you that you have hit the wrong key on a piano. When he pressed a correct one, a high-pitched tone sounded. Now he both had to remember the correct key and figure out the next one, and the next six after that. Throughout his trial-and-error ordeal, PET scans showed, the man's brain was ablaze with activity. In particular, the prefrontal cortex, parietal cortex, anterior cingulate, caudate, and cerebellum were very active; all are involved in planning, thinking, and moving.

When the young man finally worked out the correct sequence, he was instructed to keep tapping it out until he could do so effortlessly and without error. After an hour, though he was beginning to rebel at the boredom of it all, his fingers could fly over the keypad as if on automatic pilot. In fact, they were: he could tap out the sequence flawlessly while verbally repeating strings of six digits, or even while generating lists of verbs. The effortless automaticity was reflected in a marked change in his brain: according to the PET scan, the man's brain had shut off the lights in numerous regions as if they were offices at quitting time. Although his brain was still remembering the eight keys in order, and signaling the fingers how to move, the mental and cerebral activity behind that output had diminished dramatically. Only motor regions, which command the fingers to move, remained active.

Passingham then took the experimental step that really caught my eye because of its implications for my own nascent theory of directed mental force. What happens in the brain, he asked, if the person carrying out an automatic task suddenly makes a special effort to pay attention to that task? The PET scan kicked out the answer. When the young man again focused on the now-automatic keypad movements, his prefrontal cortex and anterior cingulate jerked awake, becoming metabolically active once again. This is a finding of tremendous importance, for it shows that mindful awareness has an activating effect on the brain, lighting it up. The take-home message of Passingham's studies is that willfully engaging in mindful awareness while performing an automatic task activates the action-monitoring circuitry of the prefrontal cortex. It is this activation that can transform us from automatons to members in good standing of the species *Homo sapiens* (from Latin *sapere*, "to be wise"). Given the strong evidence for the involvement of the prefrontal cortex in the willful selection of self-initiated responses, the importance of knowing we can modulate the brain activity in that very area with a healthy dose of mindfulness can't be overstated.

More evidence for the capacity of willfully directed attention to activate a specialized brain region has come from Nancy Kanwisher's lab at MIT. She and others had already demonstrated that a specific brain area, located where the temporal and occipital lobes meet, is specialized for processing the appearance of faces. Kanwisher had named this the *fusiform face area*. Does the appearance of a face activate this area automatically, or can you modulate that activity through attention? To find out, Kanwisher's team had eight volunteers view a screen that briefly displayed two faces and two houses simultaneously. Before the images appeared, the researchers told each volunteer to take note of the faces in some trials, or of the houses in others. All four images appeared each time but stayed on the screen for a mere one-fifth of a second. Then the volunteers had to determine whether the cued items (faces or houses) were a matching pair. They were able to do this accurately a little more than three-quarters of the time. The key finding: the brain's specialized face-detecting area was significantly more activated when the subjects were actively looking at faces to see whether they matched than when the faces were only viewed passively because the houses were the cued target. In other words, although both the faces and the houses impinged on the retina and the rest of the visual system (including the fusiform face area), choosing actively to focus attention on the face instantly ramped up activity in the brain's specialized face-recognition area. Its activity, that is, is not strictly automatic, "but depends instead on the allocation of voluntary attention," as the MIT team stated it. Their subsequent work has shown that attention can also ramp up activity in the brain's specialized area for recognizing places, including houses and buildings. And it's not only attention to the outside world that reaches us through our senses that causes such increased activity. Similar activations occur when you conjure up an image in your mind's eye. Thus the willful act of forming a mental image of a familiar face or place with your eyes closed selectively activates the very same face or place area of the brain that seeing the face or place with your eyes does. "We are not passive recipients but active participants in our own process of perception," Kanwisher summed up.

It is pretty clear, then, that attention can control the brain's sensory processing. But it can do something else, too, something that we only hinted at in our discussion of neuroplasticity. It is a commonplace observation that our perceptions and actions do not take place in a vacuum. Rather, they occur on a stage set that has been concocted from the furniture of our minds. If your mind has been primed with the theory of *pointillism* (the use of tiny dots of primary colors to generate secondary colors), then you will see a Seurat painting in a very different way than if you are ignorant of his technique. Yet the photons of light reflecting off the Seurat and impinging on your retina, there to be conveyed as electrical impulses into your visual cortex, are identical to the photons striking the retina of a less knowledgeable viewer, as well as of one whose mind is distracted. The three viewers "see" very different paintings. Information reaches the brain from the outside world, yes—but in "an ever-changing context of internal representations," as Mike Merzenich put it. Mental states matter. Every stimulus from the world outside impinges on a consciousness that is predisposed to accept it, or to ignore it. We can therefore go further: not only do mental states matter to the physical activity of the brain, but they can contribute to the final perception even more powerfully than the stimulus itself. Neuroscientists are (sometimes reluctantly) admitting mental states into their models for a simple reason: the induction of cortical plasticity discussed in the previous chapters is no more the simple and direct product of particular cortical stimuli than the perception of the Seurat painting is unequivocally determined by the objective pattern of photons emitted from its oil colors: quite the contrary.

In late 1998 I happened on a paper by Mike Merzenich and Rob deCharms that fortified my belief that attention is the mechanism by which the mind effects the expression of volition. The two UCSF scientists noted that when an individual pays attention to some stimulus, the neurons in the cerebral cortex that represent this object show increased activation. But Merzenich and deCharms took this observation further. In addition, they noted, "the pattern of activity of neurons in sensory areas can be altered by patterns of attention, leading to measured shifts in receptive fields or tuning of individual neurons." If individual neurons can be tuned to different stimuli, depending on the mind's attentional state, they concluded, then "entire spatial maps across the cortical surface are systematically distorted by attention…[which] implies a rapid remapping of the representational functions of the cortex."

The cortex, that is, is as subject to remapping through attention as it is through the changes in sensory input described in our survey of neuroplasticity. In addition, in all three of the cortical systems where scientists have documented neuroplasticity—the primary auditory cortex, somatosensory cortex, and motor cortex—the variable determining whether or not the brain changes is not the sensory input itself but, crucially, the attentional state of the animal. In 1993 Merzenich showed that passive stimulation alone simply did not cut it. He and his students repeatedly exposed monkeys to specific sound frequencies. When the monkeys were trained to pay attention, the result was the expected tonotopic reorganization of the auditory cortex: the representation of the repeatedly heard frequency expanded. But when the monkeys were distracted by another task, and so were paying little or no attention to the tones piped into their ears, no such tonotopic expansion occurred. Inputs that the monkey does not pay attention to fail to produce long-term cortical changes; closely attended behaviors and inputs do. Let me repeat: when stimuli *identical* to those that induce plastic changes in an attending brain are instead delivered to a nonattending brain, there is no induction of cortical plasticity. Attention, in other words, must be paid.

Since attention is generally considered an internally generated state, it seems that neuroscience has tiptoed up to a conclusion that would be right at home in the canon of some of the Eastern philosophies: introspection, willed attention, subjective state—pick your favorite description of an internal mental state—can redraw the contours of the mind, and in so doing can rewire the circuits of the brain, for it is attention that makes neuroplasticity possible. The role of attention throws into stark relief the power of mind over brain, for it is a mental state (attention) that has the ability to direct neuroplasticity. In so doing, it has the power to alter the very landscape of the brain. "Experience coupled with attention leads to physical changes in the structure and future functioning of the nervous system," Merzenich and deCharms concluded. "This leaves us with a clear physiological fact…moment by moment we choose and sculpt how our ever-changing minds will work, we choose who we will be the next moment in a very real sense, and these choices are left embossed in physical form on our material selves."

I had long suspected that attention (especially mindfully directed attention) was the key to the brain changes in OCD patients I was successfully treating with the Four Steps. This was precisely why the Refocusing step was so critical: paying attention to an alternative activity was the means by which the brain changed, quieting activity in the OCD circuit. So it was gratifying to see that Merzenich had collected evidence that focusing attention was the critical action effecting neuroplastic changes in the cortex. And as we saw in Chapter 6, purely mental rehearsal of the kind Alvaro Pascual-Leone and colleagues had volunteers perform with a piano exercise—imagining themselves playing it though not actually doing so—was an early hint of the power of attention. The volunteers may not have been touching the ivories, but their intense concentration on the sequence of notes was enough to increase the representation of those fingers in the motor cortex. They were literally thinking themselves into a new brain.

Similarly, Ed Taub had shown that the more stroke patients concentrated on their tasks—the more they paid attention—the greater their functional reorganization and recovery. In stroke patients who sustain damage to the prefrontal cortex, and whose attention systems are therefore impaired, recovery is much less likely. Two months after the stroke, a simple measure of attention, such as the patient's ability to count tones presented through headphones, predicts almost uncannily how well the patient will recover motor function. The power of attention, that is, determines whether a stroke patient will remain incapacitated or not. Ian Robertson's research group at Trinity College found much the same thing: "How well people can pay attention just after a right-brain stroke predicts how well they can use their left hands two years later." If the attention circuits in the frontal lobes are damaged by the stroke, the patient recovers less well from injury to other regions of the brain than if the frontal lobes are spared.

The powers of attention being reported by neuroscientists around the world in the late 1990s made me suspect that the process of self-directed brain reorganization I continued to document in my OCD patients might also reflect the workings of attention. In particular, I wondered whether the power of attention to bias brain function might also account for an OCD patient's ability to suppress the neuronal activation caused by obsessive thoughts and strengthen the neuronal activation caused by healthy ones. But even hypothesizing that the specific action an OCD patient chooses to focus attention on (washing hands versus tinkering with the car engine) determines which neuronal representation becomes stronger and which fades away threatens to plunge us down the rabbit hole of Cartesian dualism. In the simplest formulation, do OCD patients—indeed, does any of us?—have a choice about what to pay attention to? Or is attention fully determined by passive brain mechanisms? William James, in the passages I read to Henry Stapp on Christmas Eve, recognized that either was logically possible. If attention is fully determined by a stimulus, then if you knew the precise neuronal wiring and the trillions of synapses in a human brain you could predict precisely what—which stimulus in the environment, or which of the countless thoughts percolating just below the radar of consciousness—a person would pay attention to. The materialist reductionists believe that, under those conditions, we could indeed make such a prediction.

But although we can predict with confidence some of the stimuli that will catch our attention, like the snake that leaps onto the forest path we are hiking or the *boom!* of a building being demolished, we cannot predict others. The *meaning* of experience—how the product of those trillions of synapses will be interpreted by the mind—is inexplicable if you use only materialistic terms. In the case of my OCD patients, whether they attend to the insistent inner voice telling them they left the stove on, or to the voice of mindfulness telling them that message is nothing more (or less) than the manifestation of faulty brain wiring, is *not* predictable. In this case, the ego-dystonic nature of OCD symptoms (the fact that the characteristic intrusive thoughts and urges are experienced as extraneous and alien to the self) enables most patients to distinguish clearly between the competing calls. OCD symptoms can therefore be viewed as painfully amplified versions of the mental events that pass through the mind innumerable times in the course of a day. Most of these mental events are experienced passively, and as outside volitional control; they are often described as "popping into your head." They are thoughts and ideas that may have an identifiable trigger, perhaps a melody that triggers a memory or a sight that prompts a related thought, but feel as if they arise through deterministic mental circuitry over which we have little if any control. They arise unbidden; fleeting, transitory, evanescent, they differ from the thoughts that beset OCD sufferers only in that the latter are much more insistent, discomfiting, and intrusive. OCD thoughts grab the sufferer's attention so insistently that it takes great effort to ignore them. In this way, OCD obsessions illuminate critical differences between mental events that we experience passively and with no apparent effort and those that require significant effort to focus attention on. This aspect of the disease, as I noted earlier, is what attracted me to its study: the hope that such a condition would shed light on the relationship between the mind and the brain and, in particular, on whether mind is causally efficacious in its actions on the brain.

James's dictum "Volitional effort is effort of attention" captures the way OCD patients manage to shift their brain out of pathological thought patterns and into healthy ones. In OCD, two different neural systems compete for attention. One, generated passively and by the pathological brain circuitry underlying the disease, insists you wash your hands again. The other, generated by the active, willful effort characteristic of the Four Steps, beckons to an alternative, healthy behavior, such as gardening. It is the choice of which one to allow into one's attention, which one to hold "steadily before the mind until it *fills* the mind," that shapes subsequent actions. (Even in James's time, OCD was considered a powerful model of when and how something goes wrong with the will. He himself used it as a prime example of a disease of the will.) When my OCD patients succeed in ignoring the siren call of their obsessions, they do so through the power of their attention to hold fast before the mind the image of the healthy alternative to a compulsive act. No one with an ounce of empathy would deny that this requires tremendous effort.

To Henry Stapp, the idea of attention as the motive force behind volition suggested how mind might interact with the quantum brain—how an act of mental effort could focus a stream of consciousness that would otherwise quickly become defocused. Now, for the first time since we began our informal collaboration, Stapp began contemplating a place in his theory for the notion of mental effort. To produce what he would come to call a *quantum theory of consciousness*, he had to reach back through the decades, to his student days at Berkeley in the 1950s. After earning his undergraduate degree in physics from the University of Michigan in 1950, Stapp began work on his Ph.D. thesis at the University of California, Berkeley. His aim was to erect a theoretical framework to analyze the proton-proton scattering experiments being conducted on the cyclotron by Emilio Segrè and Owen Chamberlain (who shared the 1959 Nobel Prize in physics for their discovery of the antiproton). In these experiments, incoming *protons* (the positively charged components of atomic nuclei) caromed off other protons. At first the incoming protons were *polarized* (that is, had their spin vectors aligned) in a certain, known direction. Once they hit the stationary protons they scattered away, with a different polarization. It was logical to expect that this final polarization would have something to do with the initial polarization—or as physicists say, that the polarizations would be correlated. One of Segrè and Chamberlain's bright graduate students, Tom Ypsilantis, happened to be Stapp's roommate. One day, he asked Stapp for help analyzing the scattering result. The work eventually turned into Stapp's thesis and made him familiar with particle correlations. *Correlated particles*—those separated in space or time but sharing a common origin—were soon to trigger a revolution in our understanding of reality.

Through his thesis work, Stapp became one of the first physicists to appreciate what has now become known as Bell's Theorem. John Bell worked at CERN, the sprawling physics lab outside Geneva, Switzerland, designing particle accelerators. He was not paid to do theoretical physics. Yet the soft-spoken, red-bearded Irishman produced what Stapp would, years later, call "the most profound discovery of science." In a 1964 paper, Bell addressed a seeming paradox that had bedeviled physics since 1935. In that year, Albert Einstein and two younger colleagues, Boris Podolsky and Nathan Rosen, had published a paper that had grown out of Einstein's decade-long debate with Niels Bohr about the meaning of the quantum theories that emerged in the 1920s and 1930s. Einstein was convinced that quantum theory was merely a statistical description of a deeper reality that scientists should strive to uncover. He devised countless *thought experiments* (what would happen if…?) to persuade Bohr that quantum theory was inadequate. The paper he wrote with Podolsky and Rosen (the trio became known as EPR) in 1935 proposed one of the most famous thought experiments in modern physics.

"Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?" is about a quality of physical reality called locality. *Locality* means that physical reality in one place cannot be influenced instantaneously by what someone chooses to do at the same time in some faraway place. The core of all classical notions of physical causation, locality holds that all physical effects are caused by local interactions among discrete material particles and their associated fields. Thus if two regions, each bounded in space and time, are separated by a distance so great that even light cannot travel from one to the other, then an action in one region cannot affect anything in the second.

The protagonist of the EPR paper (I am using the simplification offered by the American theoretical physicist David Bohm) is a single quantum particle called a pi meson. It decays into one electron and one positron, which speed off in opposite directions. Quantum mechanics, recall, holds that until an observer observes a property such as the location, momentum, or spin direction of a particle, that property remains undefined. But, as EPR noted, because the positron and electron originated in a single quantum state, their properties remain (according to quantum theory) forever correlated, in a curious and nonclassical state of affairs called *entanglement*. The reality of entanglement has been empirically validated numerous times, but its implications represent one of quantum mechanics' deepest mysteries. Indeed, Schrödinger called entanglement the very essence, "the essential characteristic," of quantum physics. Through entanglement, the spins of two entangled particles, for instance, are not independent. If the spin of the parent particle is, say, 3 up, then the spin of the daughter particles must be something like 1 up and 2 up, or 5 up and 2 down—anything that adds up to the original particle's spin. There is another way of looking at this. If you know the spin of the original particle, and you measure the spin of one of the daughter particles, then you can infer the spin of the other daughter particle. This is the simplest expression of entanglement.

Let's say we make such measurements, proposed EPR. We start with the pi meson's progeny, one electron and one positron. A physicist—we'll call her Alice—measures the spin of the positron after it has flown a great distance. It has flown so far that in the time it takes Alice to measure the positron's spin, not even a signal traveling at the speed of light can reach the electron. The act of measuring the positron should therefore not be able to affect any property of the electron. This is the locality principle at work. But because the positron and electron are correlated, Alice can calculate the spin of the electron, which is based on her measurement of the positron. If her measurement of the positron finds it to have spin up along the *x*-axis (the horizontal one), then, because the progenitor pi meson has 0 spin, the electron must have spin down along the *x*-axis. If instead Alice measures the positron's spin along the *y*-axis (the vertical one) and obtains, say, "left" spin, then she deduces that the electron must have "right" spin along the *y*-axis.

A problem has arisen. Quantum mechanics insists, as you recall from Chapter 8, that no quantity is a quantity until it is an observed quantity; spin directions do not exist until and unless we measure them. The spin of the electron emerging from the decay of the pi meson is supposed to consist of a superposition of up and down, or right and left. It collapses into a particular spin only if we measure the thing. (We encountered this before, when we noted that the radioactive atom threatening Schrödinger's cat is characterized by a superposition of "decayed" and "intact," collapsing into one or the other only if we peek inside the box.) But Alice, having measured the positron's spin, knows immediately what the electron's spin is. She has therefore defied the rule that quantum properties have no physical reality until they are observed. EPR presented the conflict with quantum theory this way: "If, without in any way disturbing a system, we can predict with certainty the value of a physical quantity, then there exists an element of physical reality corresponding to this physical quantity." Armed with this reasonable criterion for physical reality, EPR asserted that at the instant Alice measures the positron's spin, the electron's spin must have an existence in physical reality even though the electron cannot have been disturbed at that instant by measuring the faraway positron.

EPR were sure they had caught quantum physics in a contradiction. Bohr's Copenhagen Interpretation insisted that properties in the quantum world do not exist until we observe them. Yet in this thought experiment, the spin of the electron is real without our observing it. EPR believed that such properties do have a physical reality independent of our observations of them: location, momentum, and spin direction are elements of reality even if they are not observed. They subscribed to the philosophical position known as *realism*, the belief (antithetical to quantum physics) that quantities exist even without our observing them. To adapt an idea of Einstein's, realism means that the Moon still hangs in the sky whether or not we sneak a peek at it.

EPR had identified an apparent Achilles' heel in quantum theory. Entanglement lets Alice's decision about what to measure *here* instantaneously affect aspects of reality *there*, in violation of locality. Einstein called this long-distance effect "spooky action at a distance," and he thought it absurd—so absurd that it should be enough to sink quantum theory. If the reality of properties of the faraway electron depends on Alice's decision about what measurement to make on the positron, then quantum theory is a philosophical absurdity. Or, as they put it, "The reality of [properties of the second particle] depend upon the process of measurement carried out on the first [particle] which does not disturb the second…in any way. No reasonable definition of reality could be expected to permit this."

Physicists inclined to ponder the philosophical implications of quantum theory battled over EPR for almost thirty years before John Bell weighed in with "On the Einstein Podolsky Rosen Paradox." In this paper, he explored whether locality is indeed a property of the physical world. Locality, to repeat, means that physical reality in one place cannot be affected instantaneously by an action in some faraway place. Bell showed that any theory of reality that agrees with the predictions of quantum theory (and, again, all of the predictions of quantum theory are borne out time and again by experiment) must violate locality. Given realism, locality must be discarded as a silly superstition. The universe must be nonlocal. At a deep level, the world is much more closely interconnected than the old physics had let on. The universe must be arranged so that what one freely decides to do *here* must in certain cases influence instantaneously what is true *there*—and *there* is as far away as one would like, from the other side of the laboratory to the other side of the galaxy.

Physicists immediately got busy testing whether the correlations between entangled particles really were in accord with "spooky action at a distance." The experiments typically involve measuring the polarization of pairs of correlated photons, as in the EPR thought experiment. But these experiments were actually carried out, not just cogitated on. Technology had become available for rapidly changing the settings of the measuring device. This development allowed a series of experiments to be performed by Alain Aspect and colleagues at the University of Paris. Published in 1982, they are widely regarded as putting the final nail in the coffin of locality. Aspect's experiments measured correlations between pairs of particles. The particles were separated by so great a distance that no causal connection, no correlation, was possible unless the causation acted faster than the speed of light—instantaneously. And yet Aspect found that the correlations were indeed of the magnitude predicted by quantum mechanics. This seems to show that the physical world is nonlocal: action *here* can instantly affect conditions *there*. (This result disappointed Bell greatly, for, like Einstein, he was uneasy with the weird implications of quantum mechanics and hoped that experiments would shore up realistic, local theories.)

Aspect's conclusions were confirmed in 1997 by Niculus Gisin at the University of Geneva and colleagues. The Swiss team created pairs of entangled photons (quanta of light) and dispatched them through fiber-optic lines to two Swiss villages, Bellevue and Bernex. Aspect had confirmed nonlocality over distances of thirteen meters (the size of his experimental apparatus). Gisin's experiment covered eleven *kilometers*. By the scale of quantum physics, eleven kilometers might as well be 11 billion light-years. Yet Gisin still found that each photon of the pair seemed to know what measurement had been made on its distant partner and to behave accordingly: the photons exhibit the property specified by the measurement made on its partner. Physicists interpret the experiment as indicating that even if tests were conducted across the known universe, they would show that physical reality is nonlocal. Nonlocality appears to be an essential, foundational property of the cosmos. The world, in spite of Einstein's objections, really does seem subject to spooky action at a distance.

At some point in their contemplation of locality, people usually pull up short and ask how being able to predict the polarization of one member of a pair of entangled particles is so weird after all. If you think about it, that prediction seems not much different from a simple, classical case in which you are told that there is a pair of gloves in a drawer. If you blindly grab one and see that it is the left-hand one, you know that the other is the right-hand one. But the gloves differ from the entangled particles in a crucial way. Gloves, being macroscopic and thus describable by classical rather than quantum physics, have an identity independent of our observations. In contrast, as you may remember from Chapter 8, quantum entities have no such identity until we observe them: hence John Archibald Wheeler's conclusion "No phenomenon is a phenomenon until it is an observed phenomenon." According to quantum physics, then, neither the distant quantum particle nor its cousin here in the lab has a spin direction until a measurement fixes that direction. Up until that observation, each particle is a superposition of all possible spin values. If we measure the first particle's spin and find that it is "up," then we have simultaneously determined with equal precision that the spin of the cousin particle that has been flung to the ends of the universe has spin "down." If this property is really brought into existence by the observation that fixes its value, then an observation in one location is directly affecting reality in another, far-off place. Quantum mechanics seems to operate across vast distances instantly in this way. It is nonlocal.

The discovery of nonlocality has shaken our notions of reality and the Cartesian divorce of mind from matter to their very foundations. "Many regard [the discovery of nonlocality] as the most momentous in the history of science," the science historian Robert Nadeau and the physicist Menas Kafatos wrote in their wonderful 1999 book *The Non-Local Universe: The New Physics and Matters of the Mind*. The reason, in large part, is that nonlocality overturns classical ontology. In both classical physics and (as you will recall from Chapter 1) Cartesian dualism, the inner realm of the human mind and the outer realm of the physical world lie on opposite sides of an unbridgeable chasm, leaving mind and physical reality entirely separate and no more capable of meaningful and coherent interactions than different species of salamander on opposite sides of the Grand Canyon. In a nonlocal universe, however, the separation between mind and world meets its ultimate challenge. As Nadeau and Kafatos put it, "The stark division between mind and world sanctioned by classical physics is not in accord with our scientific worldview. When non-locality is factored into our understanding of the relationship between parts and wholes in physics and biology, then mind, or human consciousness, must be viewed as an emergent phenomenon in a seamlessly interconnected whole called the cosmos." An *emergent phenomenon* is one whose characteristics or behaviors cannot be explained in terms of the sum of its parts; if mind is emergent, then it cannot be wholly explained by brain.

Within physics, the implications of nonlocality have generally been downplayed—indeed, have met with almost total silence, like an embarrassing relative at the wedding reception. Why? A good part of the reason is that no practical results seem to arise from the debate about these issues. It might amuse graduate students sitting around after midnight, pondering the meaning of reality and all that, but it didn't provide the basis for the transistor. At bottom, though, the failure to face nonlocality reflects an unease with the implication that the stark divide between mind and world sanctioned by classical physics—in which what is investigated and observed has a reality independent of the mind that observes or investigates—does not accord with what we now know. Almost all scientists, whether trained in the eighteenth century or the twenty-first and whether they articulate it or not, believe that the observer stands apart from the observed, and the act of observation (short of knocking over the apparatus, of course) has no effect on the system being observed. This attitude usually works just fine. But it becomes a problem when the observing system is the same as the system being observed—when, that is, the mind is observing the brain. Nonlocality suggests that nature may not separate ethereal mind from substantive stuff as completely as classical materialist physics assumed. It is here, when the mind contemplates itself and also the brain (as when an OCD patient recognizes compulsions as arising from a brain glitch), that these issues come to a head. In the case of a human being who is observing his own thoughts, the fiction of the dynamic separation of mind and matter needs to be reexamined.

That is what Henry Stapp began to do: explore the physics by which mind can exert a causal influence on brain. To do so, he focused on an odd quantum phenomenon called the Quantum Zeno Effect. Named for the Greek philosopher Zeno of Elea, the Quantum Zeno Effect was introduced to science in 1977 by the physicist George Sudarshan of the University of Texas at Austin and colleagues. If you like nonlocality, you'll love Quantum Zeno, which puts the spookiness of nonlocality to shame: in Quantum Zeno, the questions one puts to nature have the power to influence the dynamic evolution of a system. In particular, repeated and closely spaced observations of a quantum property can freeze that property in place forever, or at least much longer than it would otherwise stay if unwatched.

Consider an atom that has absorbed a photon of energy. That energy has kicked one of the atom's electrons into what's called a higher orbital, kind of like a supermassive asteroid's kicking Mercury into Venus's orbit, and the atom is said to be "excited." But the electron wants to go back where it came from, to its original orbital, as it can do if the atom releases a photon. When the atom does so is one of those chance phenomena, such as when a radioactive atom will decay: the atom has some chance of releasing a photon (and allowing the electron to return home) within a given period. Thus the excited atom exists as a superposition of itself and the unexcited state it will fall into after it has released a photon. Physicists can measure whether the atom is still in its initial state or not. If they carry out such measurements repeatedly and rapidly, they have found, they can keep the atom in its initial state. This is the Quantum Zeno Effect: such a rapid series of observations locks a system into that initial state. The more frequent the observations of a quantum system, the greater the suppression of transitions out of the initial quantum state. Taken to the extreme, observing continuously whether an atom is in a certain quantum state keeps it in that state forever. For this reason, the Quantum Zeno Effect is also known as the watched pot effect. The mere act of rapidly asking questions of a quantum system freezes it in a particular state, preventing it from evolving as it would if we weren't peeking. Simply observing a quantum system suppresses certain of its transitions to other states.

How does it work? Consider this experiment. An ammonia molecule consists of a single atom of nitrogen and three atoms of hydrogen. The arrangement of the four atoms shifts over time because all the atoms are in motion. Let's say that at first the nitrogen atom sits atop the three hydrogens, like an egg nestled on a tripod. (The nitrogen atom has only two options, to be above or below the trio. It cannot be in between.) The wave function that describes the position of the nitrogen is almost entirely concentrated in this configuration: that is, the probability of finding the nitrogen at the apex is nearly 100 percent. Left to its own devices, the wave function would shift as time went by, reflecting the increasing probability that the nitrogen atom would be found below the hydrogens. But before the wave function shifts, we make an observation. The act of observation causes the wave function (which, again, describes the probability of the atom's being in this place or that one) to collapse from several probabilities into a single actuality. This much is standard quantum theory, the well-established collapse of the wave function that follows an observation.

But something interesting has happened. "The wave function has ceased oozing toward the bottom," as Sudarshan and his colleague Tony Rothman explained, "it has been 'reset' to the zero position. And so, by repeated observations at short intervals,…one can prevent the nitrogen atom from ever leaving the top position." If you rapidly and repeatedly ask a system, Are you in this state or are you not? and make observations designed to ascertain whether or not the nitrogen atom is where it began, the system will not evolve in the normal way. It will become, in a sense, frozen. As Stapp puts it, "An answer of 'yes' to the posed question [in this case, Is the nitrogen atom on top?] will become fixed and unchanging. The state will be forced to stay longer within the realm that provides a yes answer." Quantum Zeno has been verified experimentally many times. One of the neatest confirmations came in a 1990 study at the National Institute of Standards and Technology. There, researchers measured the probability that beryllium ions would decay from a high-energy to a low-energy state. As the number of measurements per unit time increased, the probability of that energy transition fell off; the beryllium atoms stayed in their initial, high-energy state because scientists kept asking them, "So, have you decayed yet?" The watched pot never boiled. As Sudarshan and Rothman conclude, "One really can stop an atomic transition by repeatedly looking at it."

The Quantum Zeno Effect "fit beautifully with what Jeff was trying to do," recalls Henry Stapp. It was clear to Stapp, at least in principle, that Quantum Zeno might allow repeated acts of attention—which are, after all, observations by the mind of one strand of thought among the many competing for prominence in the brain—to affect quantum aspects of the brain. "I saw that if the mind puts to nature, in rapid succession, the same repeated question, 'shall I attend to this idea?' then the brain would tend to keep attention focused on that idea," Stapp says. "This is precisely the Quantum Zeno Effect. The mere mental act of rapidly attending would influence the brain's activity in the way Jeff was suggesting." The power of the mind's questioning ("Shall I pay attention to this idea?") to strengthen one idea rather than another so decisively that the privileged idea silences all the others and emerges as the one we focus on—well, this seemed to be an attractive mechanism that would not only account for my results with OCD patients but also fit with everyone's experience that focusing attention helps prevent the mind from wandering. Recall that Mike Merzenich had found that only attended stimuli have the power to alter the cortical map, expanding the region that processes the stimuli an animal focuses on. And recall Alvaro Pascual-Leone's finding that the effort of directed attention alone can produce cortical changes comparable to those generated by physical practice at the piano. It seemed at least possible that it was my OCD patients' efforts at attention, in the step we called Refocusing, that caused the brain changes we detected on PET scans.

In this way, Quantum Zeno could provide a physical basis for the finding that systematic mental Refocusing away from the insistent thoughts of OCD and onto a functional behavior can keep brain activity channeled. Mindfulness and mental effort would then be understood as a way of using attention to control brain state by means of the Quantum Zeno Effect. As Stapp told a 1998 conference in Claremont, California, "The mere choice of which question is asked can influence the behavior of a system…. [O]ne's [own] behavior could be influenced in this way by focusing one's attention, if focusing attention corresponds to specifying which question is posed." The Quantum Zeno Effect, he suggested, "could be connected to the psychological experience that intense concentration on an idea tends to hold it in place." Because quantum theory does not specify which question is put to nature or when—the dynamical gap we explored in Chapter 8—there may exist in nature "an effective force associated with mind that is not controlled by the physical aspects of nature," Stapp suggested. "Such a force could control some physical aspect of nature, namely the way a feature of the brain that is directly related to experience deviates, in a way controlled by the observer's focus of attention, from its normal evolution under the influence of physical forces alone."

Stapp began to hammer out the mathematical details by which the Quantum Zeno Effect and nonlocality would allow mental action to be causally efficacious on the brain. He had long recognized, as discussed in Chapter 8, that the Heisenberg choice—What question shall we pose to nature?—provides the basis for a mechanism by which the choice of question determines which of its faces nature deigns to reveal. But the choice of question can be construed as something even more familiar, namely, the choice of what to focus attention on. By the winter of 1999–2000, it was clear to Stapp and me that attention offered an avenue into a scientific understanding of the origin and physics-based mechanism of mental force. It thus offered the hope of understanding how directed mental force acts when OCD patients, by regularly choosing a healthy behavior over a compulsion, alter the gating function of their caudate nucleus in a way that changes the neural circuitry underlying their disease.

What did we know about OCD patients who were following the Four Steps? For one thing, a successful outcome requires that a patient make willful changes in the meaning or value he places on the distressing "error" signals that the brain generates. Only by Relabeling and Revaluing these signals can the patient change the way he processes and responds to them. Once he understands the real nature of these false brain messages, the patient can actively Refocus attention away from the obsessive thoughts. Both the PET scans and the clinical data suggest that the quality of the attentional state—that is, whether it is mindful or unmindful—influences the brain and affects how, and even whether, patients actively process or robotically experience sensory stimuli as well as emotions and thoughts.

A major question now arises. How does the OCD patient focus attention away from the false messages transmitted by the faulty but well-established OCD circuit ("Count the cans in the pantry again!") and toward the barely whispered "true" messages ("No, go feed the roses instead") that are being transmitted by the still-frail circuits that therapy is coaxing into existence? Later on, once the "true" messages have been attended to and acted on for several weeks, they will probably have affected the gating of messages through the caudate and be ever-easier to act on. But early in therapy this process is weak, even nonexistent. It is not at all obvious how a patient heeds the healthy signal, which is just taking shape in his cortex and beginning to forge a new neural pathway through his caudate, and ignores the much more insistent one being generated incessantly by his firmly entrenched and blazingly hyperactive orbital frontal cortex–basal ganglia "error message" circuitry. And once appropriate attention has been paid, how does he activate the motor circuitry that will take him away from the pantry and toward the rose garden? This last is an especially high hurdle, given that movement toward the pantry followed by obsessive counting has been the patient's habitual response to the OCD urge for years. As a result, the maladaptive motor response has its own very well-established brain circuitry in the basal ganglia.

In the buzz of cerebral activity inside the brain, our subjective sense tells us that there arise countless choices, some of them barely breaking through to consciousness. If only for an instant, we hold in our mind a representation of those possible future states—washing our hands or walking into the garden to do battle with the weeds. Those representations have real, physical correlates in different brain states. As researchers such as Stephen Kosslyn of Harvard University have shown, mental imagery activates the same regions of the brain that actual perception does. Thus thinking about washing one's hands, for instance, activates some of the same critical brain structures that actual washing activates, especially at those critical moments when the patient forms the mental image of standing at the sink and washing. "The intended action is represented…as a mental image of the intended action, and as a corresponding representation in the brain," says Stapp. In a quantum brain, all the constituents that make up a thought—the diffusion of calcium ions, the propagation of electrons, the release of neurotransmitter—exist as quantum superpositions. Thus the brain itself is characterized by a whole slew of quantum superpositions of possible brain events. The result is a buzzing confusion of alternatives, a more complex version of Schrödinger's alternative (alive or dead) cats. The alternative that persists longer in attention is the one that is caught by a sequence of rapid consents that activates the Quantum Zeno Effect.

This, Henry thought, provided the opening through which attention could give rise to volition. In the brain, the flow of calcium ions within nerve terminals is subject to the Heisenberg Uncertainty Principle. There is a probability associated with whether the calcium ions will trigger the release of neurotransmitter from a terminal vesicle—a probability, that is, and not a certainty. There is, then, also a probability but not a certainty that this neuron will transmit the signal to the next one in the circuit, without which the signal dies without leading to an action. Quantum theory represents these probabilities by means of a superposition of states. Just as an excited atom exists as a superposition of the states "Decay" and "Don't decay," so a synapse exists as a superposition of the states "Release neurotransmitter" and "Don't release neurotransmitter." This superposition corresponds to a superposition of different possible courses of action: if the "Release neurotransmitter" state comes out on top, then neuronal transmission takes place and the thought that this neuron helps generate is born. If the "Don't release neurotransmitter" state wins, then the thought dies before it is even born. By choosing whether and/or how to focus on the various possible states, the mind influences which one of them comes into being.

The more Stapp thought about it, the more he believed that attention picks out one possibility from the cloud of possibilities being thrown up for consideration by the brain. In this case, the choice is which of the superpositions will be the target of our attentional focus. Putting a question to nature, the initial step in collapsing the wave function from a sea of potentialities into one actuality, is then akin to asking, Shall this particular mental event occur? Effortfully attending to one of the possibilities is equivalent to increasing the rate at which these questions to nature are posed. Through the Quantum Zeno Effect, repeatedly and rapidly posing that question affects the behavior of the observed system—namely, the brain. When the mind chooses one of the many possibilities to attend to, it partially freezes into being those patterns of neuronal expression that correspond to the experience of an answer "yes" to the question, Will I do this?

One of the most important, and understandable, quantum processes in the human brain is the migration of calcium ions from the channels through which they enter neuron terminals to the sites where they trigger the release of neurotransmitter from a vesicle. This is a probabilistic process: the ions might or might not trigger that release, with the result that the postsynaptic neuron might or might not fire. Part of this lack of certainty is something even a physicist of the nineteenth century would have understood, it arises from factors like thermal fluctuations and other "noise." But there is, in addition to that lack of certainty, one arising from quantum effects, in particular from the Heisenberg Uncertainty Principle. According to the rules of quantum mechanics, therefore, you get a quantum splitting of the brain into different branches. This occurs in the following manner: since the channel through which the calcium ion must pass to get inside the neuron terminal is extremely narrow (less than one nanometer), it is necessary to apply the Uncertainty Principle. Specifically, since the position of the ion in the channel is extremely restricted, the uncertainty in its velocity must be very large. What this means is that the area in which the ion might land balloons out as it passes from the channel exit to the potential triggering site. Because of this, when the calcium ion gets to the area where it might trigger release of neurotransmitter, it will exist in a superposition of hitting/missing the critical release-inducing site. These quantum effects will generate a superposition of two states: the state in which the neurotransmitter in a vesicle is released, and the state in which the neurotransmitter is not released. Due to this quantum splitting, the brain will tend to contain components that specify alternative possible courses of action. That is, the evolution of the state of the brain in accordance with the Schrödinger equation will normally cause the brain to evolve into a growing ensemble of alternative branches, each representing the neural correlate of some possible conscious experience. Each of these neural correlates has an associated probability of occurring (that is, a probability of being turned from potentiality into actuality by a quantum collapse).

Which possible conscious experience will in fact occur? As noted in Chapter 8, the founders of quantum theory recognized that the mind of the experimenter or observer plays a crucial role in determining which facet of itself nature will reveal. The experimenter plays that role simply by choosing which aspect of nature he wants to probe; which question he wants to ask about the physical world; what he wants to attend to. In this model the brain does practically everything. But mind, by consenting to the rapid re-posing of the question already constructed and briefly presented by brain, can influence brain activity by causing this activity to stay focused on a particular course of action.

Let's take the example of a person suffering from OCD. In this case, one possible brain state corresponds to "Wash your hands again." Another is, "Don't wash—go to the garden." By expending mental effort—or, as I think of it, unleashing mental force—the person can focus attention on this second idea. Doing so, as we saw, brings into play the Quantum Zeno Effect. As a result, the idea—whose physical embodiment is a physical brain state—"Go to the garden" is held in place longer than classical theory predicts. The triumphant idea can then make the body move, and through associated neuroplastic changes, alter the brain's circuitry. This will change the brain in ways that will increase the probability of the "Go to the garden" brain state arising again. (See schematic on Chapter 10.)

Mindfulness and its power to help patients effectively Refocus attention seemed to explain how OCD patients manage to choose one thought over a more insistent one. This willful directing of attention can act on the brain to alter its subsequent patterns of activity, for Refocusing on useful behaviors activates the brain circuitry needed to perform them. In this way, brain circuitry is shaped by attentional mechanisms, just as the Quantum Zeno Effect predicts. If it is done regularly, as during the Four Steps, the result is not only a change in behavioral outcome—refusing to accede to the demands of the compulsive urge and instead initiating a healthy behavior—but also a change in the metabolic activity of regions of the brain whose overactivity underlies OCD. Mindfully directed attention is the indispensable factor that brings about the observed brain changes. In consciously rejecting the urge to act on the insistent thoughts of OCD, patients choose alternative and more adaptive behaviors through the willful redirection of attention, with the result that they systematically alter their own brain chemistry, remodeling neuronal circuits in a measurable way. The result is what the late cognitive scientist Francisco Varela recently called "the bootstrapping effect of [mental] action modifying the dynamical landscape" of both consciousness and its neural correlates in the brain.

Once again, William James had sketched the outlines for the emerging theory a century ago. "This coexistence with the triumphant thought of other thoughts…would inhibit it but for the effort which makes it prevail," he wrote in *Principles*. "The effort to *attend* is therefore only a part of what the word 'will' covers; it covers also the effort to *consent* to something to which our attention is not quite complete…. So that although attention is the first and fundamental thing in volition, *express consent to the reality of what is attended to* is often an additional and quite distinct phenomenon involved." For the stroke victim, the OCD patient, and the depressive, intense effort is required to bring about the requisite

Refocusing of attention—a refocusing that will, in turn, sculpt anew the ever-changing brain. The patient generates the mental energy necessary to sustain mindfulness and so activate, strengthen, and stabilize the healthy circuitry through the exertion of willful effort. This effort generates mental force. This force, in its turn, produces plastic and enduring changes in the brain and hence the mind. Intention is made causally efficacious through attention.

Through this mechanism, the mind can enter into the causal structure of the brain in a way that is not reducible to local mechanical processes—to, that is, electrochemical transmission from one neuron to the next. This power of mind gives our thoughts efficacy, and our volition power. Intention governs attention, and attention exerts real, physical effects on the dynamics of the brain. When I worked out my Four Step treatment of OCD, I had no idea that it would be in line with the quantum mechanical understanding of mind-brain dynamics. I knew that Refocusing and Revaluing make sense psychologically and strongly suspected that these mental/experiential components tap into the power of attention and thus intention to influence brain activity. But which actual physical processes were involved, I had no idea. But now, thanks to Henry Stapp, I do. It is quantum theory that permits willful redirection of attention to have real causal efficacy. In Chapter 1, we explored the conflict between science and moral philosophy posed by Cartesian dualism, and how the two realms Descartes posited—the physical and the mental—have no coherent way to interact. This conflict, devastating in its implications, is now on the verge of being resolved. For quantum theory elegantly explains how our actions are shaped by our will, and our will by our attention, which is not strictly controlled by any known law of nature.

A little humility is in order. Philosophers of an earlier time founded their worldview, materialism, on a set of physical laws associated with Newton and other scientists of the seventeenth century. Those laws turned out to be incomplete and, in their philosophical implications, misleading, especially insofar as they turn the world into a predetermined machine devoid of real moral content. Today, as we derive a scientific worldview from quantum mechanics, we cannot be sure that this theory, too, will not be superseded. For now, however, we are left with the fact that the laws of nature, as Wigner elegantly stated in the epigraph at the beginning of this book, cannot be written without appeal to consciousness. The human mind is at work in the physical universe. The effect of attention on the brain offers a rational, coherent, and intuitively satisfying explanation for the interaction between mind and brain, and for the causal efficacy of mental force. It describes the action of the mind as we actually experience it. Consciousness acts on, and acts to create out of an endless universe of predetermined possibilities, the material world—including the brain. Mental effort can speed up the rate at which attention is focused and questions are posed. This speeding up, through the Quantum Zeno Effect, tends to sustain a unified focus on one aspect of reality—which prevents the selected stream of consciousness from losing focus and diffusing. Quantum theory, with the Quantum Zeno Effect, seems to explain how human volition acts in our lives.

Figure 8 Quantum Effects of Attention

The rules of quantum mechanics allow attention to influence brain function.The release of neurotransmitters requires calcium ions to pass through ion channels in a neuron. Because these channels are extremely narrow, quantum rules and the Uncertainty Principle apply. Since calcium ions trigger vesicles to release neurotransmitters, the release of neurotransmitter is only probabilistic, not certain. In quantum language, the wave function that represents "release neurotransmitter" in a superposition with the wave function that represents release neurotransmitter" each has a probability between 0% and 100% of becoming real. Neurotransmitter release is required to keep a thought going; as a result, whether the "wash hands" or "garden" thought prevails is also a matter of probability. Attention can change the odds on which wave function, and hence which thought, wins:

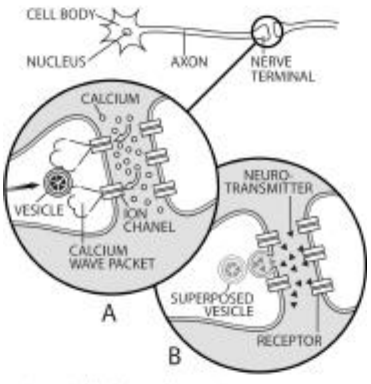
1 In OCD, the brain circuit representing "wash your hands," for instance, fires over and over.This reflects overactivity in the OCD circuit, which includes the orbital frontal cortex, anterior cingulate gyrus, and caudate nucleus.

4 The quantum rules allow both states—"release" and "don't release"—to co-exist. Early in therapy, however, the wave representing "release neurotransmitter" in the OCD circuit has a higher probability than the wave

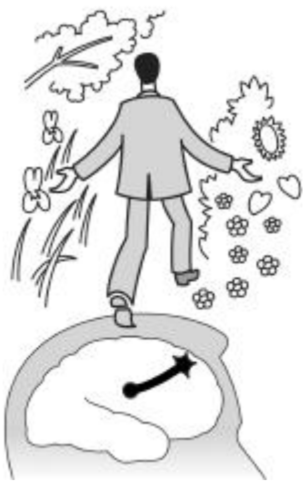
representing "release neurotransmitter" in the garden circuit. The patient is much more likely to go to the sink.

5 By expending mental effort and thus unleashing mental force, however, the OCD patient is able, by virtue of the laws of quantum mechanics, to change the odds. Focusing attention on the "garden" thought increases the probability that neurotransmitter will be released in that circuit, not the "wash" circuit.

2 Therapy introduces the idea that the OCD patient might go to the garden instead of to the sink.This idea activates planning circuits in the brain's prefrontal cortex. Early in therapy, this circuit is much weaker than the OCD circuit: it has a lower probability of occurring.



3 The vesicle exists as a superposition of quantum wave functions, one representing "release" and one representing "don't release." This is true in the brain circuit for washing as well as for gardening.



6 The OCD patient can now act on this thought and go to the garden. This increases the chance that, in the future, the "garden" circuit will prevail over the "wash" circuit.

7 If the patient regularly goes to the garden instead of the sink, neuroplasticity kicks in: brain metabolism changes in a way that strengthens the therapeutic circuit. As a result, future OCD urges are easier to overcome.

For scientifically minded people seeking a rational basis for the belief that truly ethical action is possible, James's epigram—"Volitional effort is effort of attention"—must replace *Cogito ergo sum* as the essential description of the way we experience ourselves and our inner lives. The mind creates the brain. We have the ability to bring will and thus attention to bear on a single nascent possibility struggling to be born in the brain, and thus to turn that possibility into actuality and action. The causal efficacy of attention and will offers the hope of healing the rift, opened by Cartesian dualism, between science and moral philosophy. It is time to explore the closing of this divide, and the meaning that has for the way we live our lives.