

STORIES of PERSONAL TRIUMPH from
the FRONTIERS OF BRAIN SCIENCE

The BRAIN that
CHANGES
ITSELF



Norman Doidge, M.D.

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**Stories of Personal Triumph
from the Frontiers of Brain Science**

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A James H. Silberman Book

VIKING

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Published by the Penguin Group Penguin Group (USA) Inc., 375 Hudson Street, New York, New York 10014, U.S.A. Penguin Group (Canada), 90 Eglinton Avenue East, Suite 700, Toronto, Ontario, Canada M4P 2Y3 (a division of Pearson Penguin Canada Inc.) Penguin Books Ltd, 80 Strand, London WC2R 0RL, England Penguin Ireland, 25 St. Stephen's Green, Dublin 2, Ireland (a division of Penguin Books Ltd) Penguin Books Australia Ltd, 250 Camberwell Road, Camberwell, Victoria 3124, Australia (a division of Pearson Australia Group Pty Ltd) Penguin Books India Pvt Ltd, 11 Community Centre, Panchsheel Park, New Delhi-110 017, India Penguin Group (NZ), 67 Apollo Drive, Mairangi Bay, Auckland 1311, New Zealand (a division of Pearson New Zealand Ltd) Penguin Books (South Africa) (Pty) Ltd, 24 Sturdee Avenue, Rosebank, Johannesburg 2196, South Africa

Penguin Books Ltd, Registered Offices:
80 Strand, London WC2R 0RL, England

First published in 2007 by Viking Penguin,
a member of Penguin Group (USA) Inc.

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Library of Congress Cataloging-in-Publication Data

Doidge, Norman.

The Brain that changes itself: stories of personal triumph from the frontiers of brain science /
Norman Doidge.

p. cm.

ISBN: 1-101-14711-3

1.Neuroplasticity. 2. Brain damage—Patients—Rehabilitation. I. Title.

QP363.3.D65 2007

612.8—dc22

2006049224

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For Eugene L. Goldberg, M.D.,
because you said you might like to read it

Contents

Note to the Reader

Preface

1

A Woman Perpetually Falling...
Rescued by the Man Who Discovered
the Plasticity of Our Senses

2

Building Herself a Better Brain
A Woman Labeled “Retarded” Discovers
How to Heal Herself

3

Redesigning the Brain
A Scientist Changes Brains to Sharpen Perception and
Memory, Increase Speed of Thought, and
Heal Learning Problems

4

Acquiring Tastes and Loves
What Neuroplasticity Teaches Us About
Sexual Attraction and Love

5

Midnight Resurrections
Stroke Victims Learn to Move and Speak Again

6

Brain Lock Unlocked
Using Plasticity to Stop Worries, Obsessions,
Compulsions, and Bad Habits

7

Pain

The Dark Side of Plasticity

8

Imagination

How Thinking Makes It So

9

Turning Our Ghosts into Ancestors

Psychoanalysis as a Neuroplastic Therapy

10

Rejuvenation

The Discovery of the Neuronal Stem Cell and Lessons for Preserving Our
Brains

11

More than the Sum of Her Parts

A Woman Shows Us How Radically Plastic the Brain Can Be

Appendix 1

The Culturally Modified Brain

Appendix 2

Plasticity and the Idea of Progress

Acknowledgments

Notes and References

Index

Note to the Reader

All the names of people who have undergone neuroplastic transformations are real, except in the few places indicated, and in the cases of children and their families.

The Notes and References section at the end of the book includes comments on both the chapters and the appendices.

Preface

This book is about the revolutionary discovery that the human brain can change itself, as told through the stories of the scientists, doctors, and patients who have together brought about these astonishing transformations. Without operations or medications, they have made use of the brain's hitherto unknown ability to change. Some were patients who had what were thought to be incurable brain problems; others were people without specific problems who simply wanted to improve the functioning of their brains or preserve them as they aged. For four hundred years this venture would have been inconceivable because mainstream medicine and science believed that brain anatomy was fixed. The common wisdom was that after childhood the brain changed only when it began the long process of decline; that when brain cells failed to develop properly, or were injured, or died, they could not be replaced. Nor could the brain ever alter its structure and find a new way to function if part of it was damaged. The theory of the unchanging brain decreed that people who were born with brain or mental limitations, or who sustained brain damage, would be limited or damaged for life. Scientists who wondered if the healthy brain might be improved or preserved through activity or mental exercise were told not to waste their time. A neurological nihilism—a sense that treatment for many brain problems was ineffective or even unwarranted—had taken hold, and it spread through our culture, even stunting our overall view of human nature. Since the brain could not change, human nature, which emerges from it, seemed necessarily fixed and unalterable as well.

The belief that the brain could not change had three major sources: the fact that brain-damaged patients could so rarely make full recoveries; our inability to observe the *living* brain's microscopic activities; and the idea—dating back to the beginnings of modern science—that the brain is like a glorious machine. And while machines do many extraordinary things, they don't change and grow.

I became interested in the idea of a changing brain because of my work as a research psychiatrist and psychoanalyst. When patients did not progress psychologically as much as hoped, often the conventional medical wisdom was that their problems were deeply “hardwired” into an unchangeable brain. “Hardwiring” was another machine metaphor coming from the idea of the brain as computer hardware, with permanently connected circuits, each designed to perform a specific, unchangeable function.

When I first heard news that the human brain might not be hardwired, I had to investigate and weigh the evidence for myself. These investigations took me far from my consulting room.

I began a series of travels, and in the process I met a band of brilliant scientists, at the frontiers of brain science, who had, in the late 1960s or early 1970s, made a series of unexpected discoveries. They showed that the brain changed its very structure with each different activity it performed, perfecting its circuits so it was better suited to the task at hand. If certain “parts” failed, then other parts could sometimes take over. The machine metaphor, of the brain as an organ with specialized parts, could not fully account for changes the scientists were seeing. They began to call this fundamental brain property “neuroplasticity.”

Neuro is for “neuron,” the nerve cells in our brains and nervous systems. *Plastic* is for “changeable, malleable, modifiable.” At first many of the scientists didn’t dare use the word “neuroplasticity” in their publications, and their peers belittled them for promoting a fanciful notion. Yet they persisted, slowly overturning the doctrine of the unchanging brain. They showed that children are not always stuck with the mental abilities they are born with; that the damaged brain can often reorganize itself so that when one part fails, another can often substitute; that if brain cells die, they can at times be replaced; that many “circuits” and even basic reflexes that we think are hardwired are not. One of these scientists even showed that thinking, learning, and acting can turn our genes on or off, thus shaping our brain anatomy and our behavior—surely one of the most extraordinary discoveries of the twentieth century.

In the course of my travels I met a scientist who enabled people who had been blind since birth to begin to see, another who enabled the deaf to hear; I spoke with people who had had strokes decades before and had been declared incurable, who were helped to recover with neuroplastic treatments; I met people whose learning disorders were cured and whose IQs were raised; I saw evidence that it is possible for eighty-year-olds to sharpen their memories to function the way they did when they were fifty-five. I saw people rewire their brains with their thoughts, to cure previously incurable obsessions and traumas. I spoke with

Nobel laureates who were hotly debating how we must rethink our model of the brain now that we know it is ever changing.

The idea that the brain can change its own structure and function through thought and activity is, I believe, the most important alteration in our view of the brain since we first sketched out its basic anatomy and the workings of its basic component, the neuron. Like all revolutions, this one will have profound effects, and this book, I hope, will begin to show some of them. The neuroplastic revolution has implications for, among other things, our understanding of how love, sex, grief, relationships, learning, addictions, culture, technology, and psychotherapies change our brains. All of the humanities, social sciences, and physical sciences, insofar as they deal with human nature, are affected, as are all forms of training. All of these disciplines will have to come to terms with the fact of the self-changing brain and with the realization that the architecture of the brain differs from one person to the next and that it changes in the course of our individual lives.

While the human brain has apparently underestimated itself, neuroplasticity isn't all good news; it renders our brains not only more resourceful but also more vulnerable to outside influences. Neuroplasticity has the power to produce more flexible but also more rigid behaviors—a phenomenon I call “the plastic paradox.” Ironically, some of our most stubborn habits and disorders are products of our plasticity. Once a particular plastic change occurs in the brain and becomes well established, it can prevent other changes from occurring. It is by understanding both the positive and negative effects of plasticity that we can truly understand the extent of human possibilities.

Because a new word is useful for those who do a new thing, I call the practitioners of this new science of changing brains “neuroplasticians.”

What follows is the story of my encounters with them and the patients they have transformed.

The Brain That Changes Itself

1

A Woman Perpetually Falling...

Rescued by the Man Who Discovered the Plasticity of Our Senses

And they saw the voices.

EXODUS 20:18

Cheryl Schiltz feels like she's perpetually falling. And because she feels like she's falling, she falls.

When she stands up without support, she looks, within moments, as if she were standing on a precipice, about to plummet. First her head wobbles and tilts to one side, and her arms reach out to try to stabilize her stance. Soon her whole body is moving chaotically back and forth, and she looks like a person walking a tightrope in that frantic seesaw moment before losing his balance—except that both her feet are firmly planted on the ground, wide apart. She doesn't look like she is only afraid of falling, more like she's afraid of being pushed.

"You look like a person teetering on a bridge," I say.

"Yeah, I feel I am going to jump, even though I don't want to."

Watching her more closely, I can see that as she tries to stand still, she jerks, as though an invisible gang of hoodlums were pushing and shoving her, first from one side, then from another, cruelly trying to knock her over. Only this gang is actually inside her and has been doing this to her for five years. When she tries to walk, she has to hold on to a wall, and still she staggers like a drunk.

For Cheryl there is no peace, even after she's fallen to the floor.

"What do you feel when you've fallen?" I ask her. "Does the sense of falling go away once you've landed?"

"There have been times," says Cheryl, "when I literally lose the sense of the feeling of the floor...and an imaginary trapdoor opens up and swallows me." Even when she has fallen, she feels she is still falling, perpetually, into an

infinite abyss.

Cheryl's problem is that her vestibular apparatus, the sensory organ for the balance system, isn't working. She is very tired, and her sense that she is in free fall is driving her crazy because she can't think about anything else. She fears the future. Soon after her problem began, she lost her job as an international sales representative and now lives on a disability check of \$1,000 a month. She has a newfound fear of growing old. And she has a rare form of anxiety that has no name.

An unspoken and yet profound aspect of our well-being is based on having a normally functioning sense of balance. In the 1930s the psychiatrist Paul Schilder studied how a healthy sense of being and a "stable" body image are related to the vestibular sense. When we talk of "feeling settled" or "unsettled," "balanced" or "unbalanced," "rooted" or "rootless," "grounded" or "ungrounded," we are speaking a vestibular language, the truth of which is fully apparent only in people like Cheryl. Not surprisingly, people with her disorder often fall to pieces psychologically, and many have committed suicide.

We have senses we don't know we have—until we lose them; balance is one that normally works so well, so seamlessly, that it is not listed among the five that Aristotle described and was overlooked for centuries afterward.

The balance system gives us our sense of orientation in space. Its sense organ, the vestibular apparatus, consists of three semicircular canals in the inner ear that tell us when we are upright and how gravity is affecting our bodies by detecting motion in three-dimensional space. One canal detects movement in the horizontal plane, another in the vertical plane, and another when we are moving forward or backward. The semicircular canals contain little hairs in a fluid bath. When we move our head, the fluid stirs the hairs, which send a signal to our brains telling us that we have increased our velocity in a particular direction. Each movement requires a corresponding adjustment of the rest of the body. If we move our heads forward, our brains tell an appropriate segment of our bodies to adjust, unconsciously, so that we can offset that change in our center of gravity and maintain our balance. The signals from the vestibular apparatus go along a nerve to a specialized clump of neurons in our brain, called the "vestibular nuclei," which process them, then send commands to our muscles to adjust themselves. A healthy vestibular apparatus also has a strong link to our visual system. When you run after a bus, with your head bouncing up and down as you race forward, you are able to keep that moving bus at the center of your gaze because your vestibular apparatus sends messages to your brain, telling it the speed and direction in which you are running. These signals allow your brain

to rotate and adjust the position of your eyeballs to keep them directed at your target, the bus.

I am with Cheryl, and Paul Bach-y-Rita, one of the great pioneers in understanding brain plasticity, and his team, in one of his labs. Cheryl is hopeful about today's experiment and is stoical but open about her condition. Yuri Danilov, the team biophysicist, does the calculations on the data they are gathering on Cheryl's vestibular system. He is Russian, extremely smart, and has a deep accent. He says, "Cheryl is patient who has lost vestibular system—ninety-five to one hundred percent."

By any conventional standard, Cheryl's case is a hopeless one. The conventional view sees the brain as made up of a group of specialized processing modules, genetically hardwired to perform specific functions and those alone, each developed and refined over millions of years of evolution. Once one of them is this damaged, it can't be replaced. Now that her vestibular system is damaged, Cheryl has as much chance of regaining her balance as a person whose retina has been damaged has of seeing again.

But today all that is about to be challenged.

She is wearing a construction hat with holes in the side and a device inside it called an accelerometer. Licking a thin plastic strip with small electrodes on it, she places it on her tongue. The accelerometer in the hat sends signals to the strip, and both are attached to a nearby computer. She laughs at the way she looks in the hat, "because if I don't laugh I will cry."

This machine is one of Bach-y-Rita's bizarre-looking prototypes. It will replace her vestibular apparatus and send balance signals to her brain from her tongue. The hat may reverse Cheryl's current nightmare. In 1997 after a routine hysterectomy, Cheryl, then thirty-nine years old, got a postoperative infection and was given the antibiotic gentamicin. Excessive use of gentamicin is known to poison the inner ear structures and can be responsible for hearing loss (which Cheryl doesn't have), ringing in the ears (which she does), and devastation to the balance system. But because gentamicin is cheap and effective, it is still prescribed, though usually for only a brief period of time. Cheryl says she was given the drug way beyond the limit. And so she became one of a small tribe of gentamicin's casualties, known among themselves as Wobblers.

Suddenly one day she discovered she couldn't stand without falling. She'd turn her head, and the whole room would move. She couldn't figure out if she or the walls were causing the movement. Finally she got to her feet by hanging on to the wall and reached for the phone to call her doctor.

When she arrived at the hospital, the doctors gave her various tests to see if

her vestibular function was working. They poured freezing-cold and warm water into her ears and tilted her on a table. When they asked her to stand with her eyes closed, she fell over. A doctor told her, “You have no vestibular function.” The tests showed she had about 2 percent of the function left.

“He was,” she says, “so nonchalant. ‘It looks like a side effect of the gentamicin.’” Here Cheryl gets emotional. “Why in the world wasn’t I told about that? ‘It’s permanent,’ he said. I was alone. My mother had taken me to the doctor, but she went off to get the car and was waiting for me outside the hospital. My mother asked, ‘Is it going to be okay?’ And I looked at her and said, ‘It’s permanent...this is never going to go away.’”

Because the link between Cheryl’s vestibular apparatus and her visual system is damaged, her eyes can’t follow a moving target smoothly. “Everything I see bounces like a bad amateur video,” she says. “It’s as though everything I look at seems made of Jell-O, and with each step I take, everything wiggles.”

Although she can’t track moving objects with her eyes, her vision is all she has to tell her that she is upright. Our eyes help us know where we are in space by fixing on horizontal lines. Once when the lights went out, Cheryl immediately fell to the floor. But vision proves an unreliable crutch for her, because any kind of movement in front of her—even a person reaching out to her—exacerbates the falling feeling. Even zigzags on a carpet can topple her, by initiating a burst of false messages that make her think she’s standing crookedly when she’s not.

She suffers mental fatigue, as well, from being on constant high alert. It takes a lot of brain power to maintain an upright position—brain power that is taken away from such mental functions as memory and the ability to calculate and reason.

While Yuri is readying the computer for Cheryl, I ask to try the machine. I put on the construction worker’s hat and slip into my mouth the plastic device with electrodes on it, called a tongue display. It is flat, no thicker than a stick of chewing gum.

The accelerometer, or sensor, in the hat detects movement in two planes. As I nod my head, the movement is translated onto a map on the computer screen that permits the team to monitor it. The same map is projected onto a small array of 144 electrodes implanted in the plastic strip on my tongue. As I tilt forward, electric shocks that feel like champagne bubbles go off on the front of my tongue, telling me that I am bending forward. On the computer screen I can see where my head is. As I tilt back, I feel the champagne swirl in a gentle wave to the back of my tongue. The same happens when I tilt to the sides. Then I close my eyes and experiment with finding my way in space with my tongue. I soon

forget that the sensory information is coming from my tongue and can read where I am in space.

Cheryl takes the hat back; she keeps her balance by leaning against the table.

“Let’s begin,” says Yuri, adjusting the controls.

Cheryl puts on the hat and closes her eyes. She leans back from the table, keeping two fingers on it for contact. She doesn’t fall, though she has no indication whatsoever of what is up and down except the swirling of the champagne bubbles over her tongue. She lifts her fingers from the table. She’s not wobbling anymore. She starts to cry—the flood of tears that comes after a trauma; she can open up now that she has the hat on and feels safe. The first time she put on the hat, the sense of perpetual falling left her—for the first time in five years. Her goal today is to stand, free, for twenty minutes, with the hat on, trying to keep centered. For anyone—not to mention a Wobbler—to stand straight for twenty minutes requires the training and skill of a guard at Buckingham Palace.

She looks peaceful. She makes minor corrections. The jerking has stopped, and the mysterious demons that seemed to be inside her, pushing her, shoving her, have vanished. Her brain is decoding signals from her artificial vestibular apparatus. For her, these moments of peace are a miracle—a neuroplastic miracle, because somehow these tingling sensations on her tongue, which normally make their way to the part of the brain called the sensory cortex—the thin layer on the surface of the brain that processes the sense of touch—are making their way, through a novel pathway in the brain, to the brain area that processes balance.

“We are now working on getting this device small enough so that it is hidden in the mouth,” says Bach-y-Rita, “like an orthodontist’s mouth retainer. That’s our goal. Then she, and anyone with this problem, will have a normal life restored. Someone like Cheryl should be able to wear the apparatus, talk, and eat without anyone knowing she has it.

“But this isn’t just going to affect people damaged by gentamicin,” he continues. “There was an article in *The New York Times* yesterday on falls in the elderly. Old people are more frightened of falling than of being mugged. A third of the elderly fall, and because they fear falling, they stay home, don’t use their limbs, and become more physically frail. But I think part of the problem is that the vestibular sense—just like hearing, taste, eyesight, and our other senses—starts to weaken as we age. This device will help them.”

“It’s time,” says Yuri, turning off the machine.

Now comes the second neuroplastic marvel. Cheryl removes the tongue device

and takes off the hat. She gives a big grin, stands free with her eyes closed, and doesn't fall. Then she opens her eyes and, still not touching the table, lifts one foot off the ground, so she's balancing on the other.

"I love this guy," she says, and goes over and gives Bach-y-Rita a hug. She comes over to me. She's overflowing with emotion, overwhelmed by feeling the world under her feet again, and she gives me a hug too.

"I feel anchored and solid. I don't have to think where my muscles are. I can actually think of other things." She returns to Yuri and gives him a kiss.

"I have to emphasize why this is a miracle," says Yuri, who considers himself a data-driven skeptic. "She has almost no natural sensors. For the past twenty minutes we provided her with an artificial sensor. But the real miracle is what is happening *now* that we have removed the device, and she doesn't have either an artificial or a natural vestibular apparatus. We are awakening some kind of force inside her."

The first time they tried the hat, Cheryl wore it for only a minute. They noticed that after she took it off, there was a "residual effect" that lasted about twenty seconds, a third of the time she wore the device. Then Cheryl wore the hat for two minutes and the residual effect lasted about forty seconds. Then they went up to about twenty minutes, expecting a residual effect of just under seven minutes. But instead of lasting a third of the time, it lasted triple the time, a full hour. Today, Bach-y-Rita says, they are experimenting to see if twenty more minutes on the device will lead to some kind of training effect, so that the residual effect will last even longer.

Cheryl starts clowning and showing off. "I can walk like a woman again. That's probably not important to most people, but it means a lot that I don't have to walk with my feet wide apart now."

She gets up on a chair and jumps off. She bends down to pick things up off the floor, to show she can right herself. "Last time I did this I was able to jump rope in the residual time."

"What is amazing," says Yuri, "is that she doesn't just keep her posture. After some time on the device, she behaves almost normally. Balancing on a beam. Driving a car. It is the recovery of the vestibular function. When she moves her head, she can keep her focus on her target—the link between the visual and vestibular systems is also recovered."

I look up, and Cheryl is dancing with Bach-y-Rita.

She leads.

How is it that Cheryl can dance and has returned to normal functioning without the machine? Bach-y-Rita thinks there are several reasons. For one, her damaged vestibular system is disorganized and “noisy,” sending off random signals. Thus, noise from the damaged tissue blocks any signals sent by healthy tissue. The machine helps to reinforce the signals from her healthy tissues. He thinks the machine also helps recruit other pathways, which is where plasticity comes in. A brain system is made of many neuronal pathways, or neurons that are connected to one another and working together. If certain key pathways are blocked, then the brain uses older pathways to go around them. “I look at it this way,” says Bach-y-Rita. “If you are driving from here to Milwaukee, and the main bridge goes out, first you are paralyzed. Then you take old secondary roads through the farmland. Then, as you use these roads more, you find shorter paths to use to get where you want to go, and you start to get there faster.” These “secondary” neural pathways are “unmasked,” or exposed, and, with use, strengthened. This “unmasking” is generally thought to be one of the main ways the plastic brain reorganizes itself.

The fact that Cheryl is gradually lengthening the residual effect suggests that the unmasked pathway is getting stronger. Bach-y-Rita hopes that Cheryl, with training, will be able to continue extending the length of the residual effect.

A few days later an e-mail for Bach-y-Rita arrives from Cheryl, her report from home about how long the residual time lasted. “Total residual time was: 3 hours, 20 minutes...The wobbling begins in my head—just like usual...I am having trouble finding words...Swimming feeling in my head. Tired, exhausted...Depressed.”

A painful Cinderella story. Coming down from normalcy is very hard. When it happens, she feels she has died, come to life, and then died again. On the other hand, three hours and twenty minutes after only twenty minutes on the machine is residual time ten times greater than the time on the device. She is the first Wobbler ever to have been treated, and even if the residual time never grows longer, she could now wear the device briefly four times a day and have a normal life. But there is good reason to expect more, since each session seems to be training her brain to extend the residual time. If this keeps up...

...It did keep up. Over the next year Cheryl wore the device more frequently to get relief and build up her residual effect. Her residual effect progressed to multiple hours, to days, and then to four months. Now she does not use the device at all and no longer considers herself a Wobbler.

In 1969, *Nature*, Europe’s premier science journal, published a short article that

had a distinctly sci-fi feel about it. Its lead author, Paul Bach-y-Rita, was both a basic scientist and a rehabilitation physician—a rare combination. The article described a device that enabled people who had been blind from birth to see. All had damaged retinas and had been considered completely untreatable.

The *Nature* article was reported in *The New York Times*, *Newsweek*, and *Life*, but perhaps because the claim seemed so implausible, the device and its inventor soon slipped into relative obscurity.

Accompanying the article was a picture of a bizarre-looking machine—a large old dentist’s chair with a vibrating back, a tangle of wires, and bulky computers. The whole contraption, made of cast-away parts combined with 1960s electronics, weighed four hundred pounds.

A congenitally blind person—someone who had never had any experience of sight—sat in the chair, behind a large camera the size of those used in television studios at the time. He “scanned” a scene in front of him by turning hand cranks to move the camera, which sent electrical signals of the image to a computer that processed them. Then the electrical signals were conveyed to four hundred vibrating stimulators, arranged in rows on a metal plate attached to the inside of the chair back, so the stimulators rested against the blind subject’s skin. The stimulators functioned like pixels vibrating for the dark part of a scene and holding still for the brighter shades. This “tactile-vision device,” as it was called, enabled blind subjects to read, make out faces and shadows, and distinguish which objects were closer and which farther away. It allowed them to discover perspective and observe how objects seem to change shape depending upon the angle from which they were viewed. The six subjects of the experiment learned to recognize such objects as a telephone, even when it was partially obscured by a vase. This being the 1960s, they even learned to recognize a picture of the anorexic supermodel Twiggy.

Everyone who used the relatively clunky tactile-vision device had a remarkable perceptual experience, as they went from having tactile sensations to “seeing” people and objects.

With a little practice, the blind subjects began to experience the space in front of them as three-dimensional, even though the information entered from the two-dimensional array on their backs. If someone threw a ball toward the camera, the subject would automatically jump back to duck it. If the plate of vibrating stimulators was moved from their backs to their abdomens, subjects still accurately perceived the scene as happening in front of the camera. If tickled near the stimulators, they didn’t confuse the tickle with a visual stimulus. Their mental perceptual experience took place not on the skin surface but in the world.