By Norman Doidge
Illustration by **Amedeo De Palma**

REDESIGNING THE BRAIN

Can we change our brains to sharpen perception and memory, increase speed of thought, and heal learning problems? Michael Merzenich is proving that we can.

UNIVERSITY OF CALIFORNIA neuroscientist **Michael Merzenich** has made the most ambitious claim in his field: that brain exercises may be as useful as drugs to treat diseases as severe as schizophrenia; that brain 'plasticity' exists from the cradle to the grave; and that radical improvements in cognitive functioning – how we learn, think, perceive, and remember – are possible, even in the elderly.

Merzenich claims that when learning occurs in a way consistent with the laws that govern brain plasticity, the 'mental machinery' of the brain can be improved so that we learn and perceive with greater precision, speed, and retention. Clearly when we learn, we increase what we know; but his claim is that we can also change the very structure of the brain itself and increase its capacity to learn.

Though he was not the first scientist to demonstrate 'neuroplasticity,' it was through experiments he conducted early in his career that mainstream neuroscientists came to accept the plasticity of the brain. "The cerebral cortex," he says of the thin outer layer of the brain, "is actually selectively refining its processing capacities to fit each task at hand." It doesn't simply learn; it is always "learning how to learn."

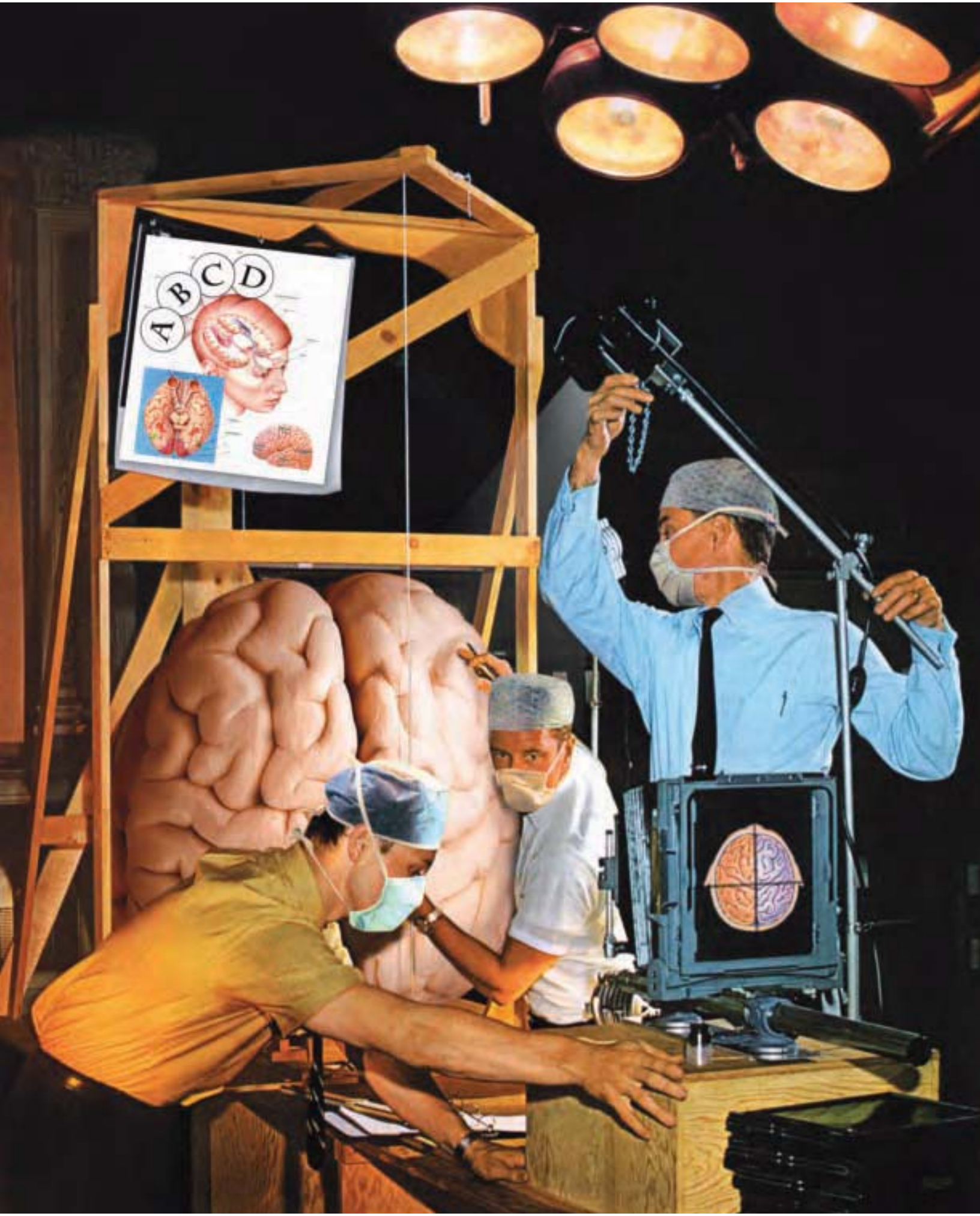
The brain Merzenich describes is not an inanimate vessel that we fill; rather it is more like a living creature with an appetite, one that can grow and change itself with proper nourishment and exercise.

Brain Mapping

To understand how 'brain maps' can change, we need first to have a picture of them. Brain maps were first made vivid in human beings by Dr. **Wilder Penfield** at the **Montreal Neurological Institute** in the 1930s. For Penfield, 'mapping' a patient's brain meant finding where in the brain different parts of the body were represented and their activities processed. Penfield discovered that the frontal lobes were the seat of the brain's *motor* system, which initiates and coordinates the movement of our muscles. The three lobes behind the frontal lobe – the temporal, parietal, and occipital lobes, comprise the brain's *sensory* system, processing the signals sent to the brain from our sense receptors – eyes, ears, touch receptors, and so on.

He spent years mapping these parts of the brain, discovering that when he touched a patient's sensory brain map with an electric probe, it triggered sensations that the patient felt in his body. Normally, when one's hand is touched, an electrical signal passes to the spinal cord and up to the brain, where it turns on cells in the map that make the hand 'feel' touched. Penfield found he could also make the patient feel his hand was touched by turning on the 'hand area' of the brain map electrically; when he stimulated another part of the map, the patient might feel his arm being touched. After many operations, he was able to show where on the brain's sensory map all parts of the body's surface were represented.

Penfield did the same for the motor map, the part of the brain that controls movement. By touching different parts of this map, he could trigger movements in a patient's leg, arm, face, and other muscles. One of his great discoveries was that brain maps, like geographical maps, are topographical, meaning that areas adjacent to each other on the body's surface are generally adjacent to each other on the brain maps. He also discovered that when he touched certain parts of the brain, he triggered long-lost childhood memories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or dreamlike scenes – which implied that higher mental activities were also mapped in the brain.

These maps shaped several generations' views of the brain. But because scientists believed that the brain couldn't change, they assumed, and taught, that these maps were fixed, immutable, and universal – the same in each of us, though Penfield himself never made either claim. Merzenich's key discovery was that brain maps are neither immutable within a single brain nor universal, but vary in their borders and size from person to person. In a series of experiments, he showed that the shape of our brain maps changes depending upon what we do over the course of our lives. Merzenich also observed that the new topographical maps were forming in slightly different places than before: maps were dynamic.

A War of Nerves

The 'competitive' nature of brain plasticity affects us all. There is an endless war of nerves going on inside each of our brains. If we stop exercising our mental skills, we do not just forget them: the brain map space for those skills is turned over to the skills we practice instead. If you ever ask yourself, "How often must I practice French, or guitar, or Math to keep on top of it?" you are asking a question about competitive plasticity. You are asking how frequently you must practice one activity to make sure its brain map space is not lost to another.

Competitive plasticity in adults even explains some of our limitations. Think of the difficulty most adults have in learning a second language. The conventional view now is that the difficulty arises because the critical period for language learning has ended, leaving us with a brain too rigid to change its structure on a large scale. But the discovery of competitive plasticity suggests there is more to it. As we age, the more we use our native language, the more it comes to dominate our linguistic map space. Thus it is also because our brain is plastic – and because plasticity is competitive – that it is so hard to learn a new language and end the tyranny of the mother tongue.

But why, if this is true, is it easier to learn a second language when we are young? Is there not competition then, too? Not really. If two languages are learned at the same time, during the critical period, both get a foothold. Brain scans of a bilingual child, says Merzenich, show that all the sounds of its two languages share a single large map, a 'library' of sounds from both languages.

Competitive plasticity also explains why our bad habits are so difficult to break or 'unlearn.' Most of us think of the brain as a container, and learning as putting something in it. When we try to break a bad habit, we think the solution is to put something new into the container. But when we learn a bad habit, it takes over a brain map, and each time we repeat it, it claims more control of that map and prevents the use of that space for 'good' habits. That is why un-learning is often a lot harder than learning, and why early childhood education is so important: it's best to get it right early, before 'bad habits' get a competitive advantage.

In a few short years Merzenich discovered that adult brains are plastic, persuaded skeptics in the scientific community that this was the case, and showed that experience changes the brain. But he still hadn't explained a crucial enigma: how brain maps organize themselves to become topographical and function in a way that is useful to us.

As mentioned earlier, when we say a brain map is organized topographically, we mean that the map is ordered as the body itself is ordered. For instance, our middle finger sits between our index finger and our ring finger. The same is true for our brain map: the map for the middle finger sits between the map for our index finger and that of our ring finger. Topographical organization is efficient, because it means that parts of the brain that often work together are close together in the brain map, so signals don't have to travel far in the brain itself. The question for Merzenich was, how does this topographic order emerge in the brain map?

The answer he and his team came to was ingenious: a topographic order emerges because many of our everyday activities involve repeating sequences in a fixed order. When we pick up an object the size of an apple or baseball, we usually grip it first with our thumb and index finger, then wrap the rest of our fingers around it one by one. Since the thumb and index finger often touch at almost the same time, sending their signals to the brain almost simultaneously, the thumb map and the index finger map tend to form close together in the brain ('neurons that fire together wire together'). As we continue to wrap our hand around the object, our middle finger will touch it next, so its brain map will tend to be beside the index finger and farther away from the thumb. As this common grasping sequence – thumb first, index finger second, middle finger third – is repeated thousands of times, it leads to a brain map where the thumb map is next to the index finger map, which is next to the middle finger map, and so on. Signals that tend to arrive at separate times, like thumbs and pinkies, have more distant brain maps, because 'neurons that fire apart wire apart.'

Many, if not all brain maps work by spatially grouping together events that happen together. As we have seen, the auditory map is arranged like a piano, with mapping regions for low notes at one end and high notes at the other. Why is it so orderly? Because the low frequencies of sounds tend to come together with one another in nature. When we hear a person with a low voice, most of the frequencies are low, so they get grouped together.

As neurons are trained and become more efficient, they can process faster. This means that the speed at which we think is itself plastic. Speed of thought is essential to our survival. Events often happen quickly, and if the brain is slow, it can miss important information. Faster neurons ultimately lead to faster thought – no minor matter, because speed of thought is a crucial component of intelligence. IQ tests, like life, measure not only whether you can get the right answer, but how long it takes you to get it.

The Role of 'BDNF'

In the late 1980s, the discovery of the nerve-growth factor known as 'brain-derived neurotrophic factor,' or BDNF, caught Merzenich's attention. BDNF plays a crucial role in reinforcing plastic changes made in the brain in the critical period. According to Merzenich, it does this in four ways.

1. When we perform an activity that requires specific neurons to fire together, they release BDNF. This growth factor consolidates the connections between those neurons and helps to wire them together so they fire together reliably in the future.
2. During the critical period BDNF turns on the nucleus basalis, the part of our brain that allows us to focus our attention – and
3. keeps it on, throughout the entire critical period. Once turned on, the nucleus basalis helps us not only pay attention but remember what we are experiencing. It allows map differentiation and change to take place effortlessly. Merzenich told me, "It is like a teacher in the brain saying, 'Now *this* is really important – this you have to know for the exam of life.'" Merzenich calls the nucleus basalis and the attention system the "modulatory control system of plasticity" – the neurochemical system that, when turned on, puts the brain in an extremely plastic state.
4. The fourth and final service that BDNF performs is to help close down the critical period. Once the main neuronal connections are laid down, there is a need for stability and hence less plasticity in the system. When BDNF is released in sufficient quantities, it turns off the nucleus basalis and ends that magical epoch of effortless learning. Henceforth, the nucleus can be activated only when something important, surprising, or novel occurs, or if we make the effort to pay close attention.

These findings open up the possibility of high-speed learning later in life. The nucleus basalis could be turned on by an electrode, by micro-injections of certain chemicals, or by drugs. It is hard to imagine that people will not – for better or for worse – be drawn to a technology that would make it relatively effortless to master the facts of Science, History, or a profession, merely by being exposed to them briefly. Imagine immigrants coming to a new country, able to pick up their new language with ease and without an accent, in a matter of months. Imagine how the lives of older people who have been laid off from a job might be transformed, if they were able to learn a new skill with the alacrity they had in early childhood. On the down side, such techniques would no doubt also be abused by high school and university students in their studies and in competitive entrance exams.

Such aggressive interventions might have unanticipated, adverse effects on the brain – not to mention our ability to discipline ourselves – but they would likely be pioneered in cases of dire medical need. For instance, turning on the nucleus basalis might help brain-injured patients, many of whom cannot relearn the lost functions of reading, writing, speaking, or walking because they can't pay close enough attention.

Preserving Brain Plasticity

Merzenich's company, **Posit Science**, is devoted to helping people preserve the plasticity of their brains as they age and extend their mental lifespans. "It's estimated that by the time someone who is 65 now dies, the life expectancy will be in the late 80s. Well, when you are 85, there is a 47 per cent chance that you will have Alzheimer's disease. So we've created this bizarre situation in which we are keeping people alive long enough so that on the average, half of them get this awful disease. We've got to do something about the mental lifespan, to extend it out and into the body's lifespan."

A major reason memory loss occurs as we age is that we have trouble registering new events in our nervous systems. Processing speed slows down, so that the accuracy, strength, and sharpness with which we perceive declines.

Merzenich thinks our neglect of intensive learning as we age leads the systems in the brain that modulate, regulate, and control plasticity to waste away. His way of attacking mental decline is at odds with mainstream Neuroscience. Thousands of papers written about the physical and chemical changes that occur in the aging brain describe processes that occur as neurons die. There are many drugs on the market designed to block these processes and raise levels of falling chemicals in the brain. Yet, Merzenich believes that such drugs provide only about four to six months of improvement.

"There is something really wrong about all this," he says. "It neglects the role of what is required to *sustain* normal skills and abilities. It is as if your skills and abilities, acquired in the brain at a young age, are just destined to deteriorate as the physical brain deteriorates." The mainstream approach, he argues, is based on no real understanding of what it takes to develop a new skill in the brain, never mind to sustain it. "It is imagined," he says, "that if you manipulate the levels of the right neurotransmitter, that memory will be recovered, and cognition will be useful, and that you will start moving like a gazelle again."

The mainstream approach doesn't take into account what is required to maintain a sharp memory. A major reason memory loss occurs as we age is that we have trouble registering new events in our nervous systems, because processing speed slows down, so that the accuracy, strength, and sharpness with which we perceive declines. If you can't register something clearly, you won't be able to remember it well.

Middle age is often an appealing time because, all else being equal, it can be a relatively placid period compared with what has come before: our bodies aren't changing as they did in adolescence; we're more likely to have a solid sense of who we are and be skilled at a career. We still regard ourselves as active, but we have a tendency to deceive ourselves into thinking that we are learning as we were before. We rarely engage in tasks in which we must focus our attention as closely as we did when we were younger, trying to learn a new vocabulary or master new skills. Such activities as reading the newspaper and practicing a profession of many years are mostly the replay of mastered skills, not learning. By the time we hit our 70s, we may not have systematically engaged the systems in the brain that regulate plasticity for 50 years.

Because it requires intense focus, studying a new language turns on the control system for plasticity and keeps it in good shape for laying down sharp memories of all kinds. Anything that requires highly-focused attention will help that system – learning new physical activities that require concentration, solving challenging puzzles, or making a career change that requires that you master new skills. Merzenich himself is an advocate of learning a new language in old age. "You will gradually sharpen *everything* up again, and that will be highly beneficial to you."

The same applies to mobility. Just doing the dances you learned years ago won't help your brain's motor cortex stay in shape. To keep the mind alive requires learning something truly new, with intense focus. That is what will allow you to both lay down new memories and have a system that can easily access and preserve the older ones.

Posit Science has developed exercises for memory of words and language, using listening exercises and computer games for auditory memory designed for adults. Instead of giving people with fading memories lists of words to memorize, as many self-help books recommend, these exercises rebuild the brain's basic ability to process sound, by getting people to listen to slowed, refined speech sounds. Merzenich says they have been able to turn back the clock on people's cognitive functioning so that their memories, problem-solving abilities, and language skills are more youthful again. "We've driven people to abilities that apply to a much more youthful person – that an 80-year-old is acting, operationally, like they are 50 or 60. Everything that you can see happen in a young brain can happen in an older brain."

In closing

Having devoted years to enlarging brain maps, Merzenich now believes there are times when you may want to shrink them. He has been working on developing a 'mental eraser' that can eliminate a problematic brain map. This technique could be of great use for people who have post-traumatic flashbacks, recurring obsessional thoughts or phobias.

Merzenich continues to challenge the view that we are stuck with the brain we have at birth. The 'Merzenich brain' is structured by its constant collaboration with the world, and it is not only the parts most exposed to it, such as our senses, that are shaped by experience. Plastic change, caused by our experience, travels deep into the brain and ultimately even into our genes, molding them as well. **R**

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The above is an excerpt from *The Brain That Changes Itself: Stories of Personal Triumph from the Frontiers of Brain Science* (Viking Penguin, 2007) by Norman Doidge, M.D.