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Mind Sculpture

Ian Robertson

About the Book

Accessible and compelling, *Mind Sculpture* explains the consequences for how we understand the brain and how we perceive ourselves.

New research has demonstrated that the brain is shaped by our experience of the world around us. As one of the world's leading authorities on brain rehabilitation, Ian Robertson is uniquely placed to explore these groundbreaking discoveries, which challenges the currently fashionable view that mental ability is predestined from birth.

Discover how:

Your brain is physically changed by what you do and think.

Education moulds your brain, growing new connections between brain cells, building brain power – it's not all down to genes.

Talking to babies builds their intelligence.

Severe fear and stress can cause brain cells to shrink and even die.

Love makes the brain grow.

MIND SCULPTURE

YOUR BRAIN’S UNTAPPED POTENTIAL

IAN ROBERTSON

BANTAM BOOKS

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To you, Fiona, my love and gratitude …
… and to you Deirdre, Ruairi and Niall – the same

IAN ROBERTSON is Professor of Psychology at Trinity College, Dublin. Formerly a scientist at the MRC Cognition and Brain Sciences Unit in Cambridge, where he was a Fellow of Hughes Hall, he is also Visiting Professor at University College, London with a further appointment in Toronto. One of the world's leading researchers on brain rehabilitation, he has published numerous scholarly books and scientific papers on the subject.

Author’s Note

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Finally, to Fiona, without whose support I could not have done this.

1
The Electric *YOU*

Listen. Can you hear an aircraft passing overhead? A dog barking? The twittering of birds? In straining to listen, you have just sent a surge of electrical activity through millions of brain cells. In choosing to do this, you have changed your brain – you have made brain cells fire, at the side of your head, above the right eye.

As you come back to reading these words, a quite different part of the brain pulses with the electricity of you. At this precise moment, your brain is sending extra blood to the left side of your brain and to the back of your brain. This is fuel for the electricity needed for a different kind of mental effort – the act of transforming these squiggles on the paper into thought.

By the time you have read this far, you will have changed your brain permanently. These words will leave a faint trace in the woven electricity of you. For 'you' exists in the trembling web of connected brain cells. This web is in flux, continually remoulded, sculpted by the restless energy of the world. That energy is transformed at your senses into that utterly unique weave of brain connections that is 'you'.

Your brain takes up a fifth of all the energy generated by your body in its resting state. It is like a 20-watt lightbulb, continuously glowing. This energy is needed to drive activity in the vast trembling web of connected cells that is your brain. And you – the captain of this amazing ship – can direct this activity, as you have just done.

That you can read these strange, arbitrary lines on the page is because people have changed your brain. Just as I am moulding the electricity of your brain connections at the moment you read this, so your parents and teachers physically sculpted your brain by what they taught you. Without this mind sculpture you would be illiterate. You were taught to read because it isn't something your brain does naturally. Had you not been taught to read, you would not be 'you'. For who 'you' are arises from the restless murmuring and urging of the world at the gates of your senses.

Through your senses, and in the trembling weave of your brain, this energy is transmuted into the electricity of you. And you, in turn, give this energy back to the universe by what you choose to do and say. Thus you are locked into an intimate embrace with the universe, the universe transforming you and you changing it.

Escape from the shackles of biology

Your brain is changed physically by the conversations you have, the events you witness and the love you receive. This is true all through your life, not just when you are an infant. Until very recently, scientists were pessimistic about the possibility of sculpting the brain through experience. This is understandable because of a stark fact which has been known for over half a century: unlike almost all the other cells in the body, brain and spinal cord cells in the main do not replace themselves. Once dead, most brain cells stay dead, although recent research has found new brain cells being produced in adults, in a part of the brain known as the hippocampus. But assuming that cells mostly can't grow, how can our brains be sculpted and our abilities enhanced by experience? We will discover the answer to this question in this book.

It is often argued that the brain is ‘hard-wired’, meaning that if the wiring is broken, or indeed if a brain never gets wired in the first place, then change is impossible. It is true that the brain *is* hard-wired to a great extent, but research over the last ten years has proved dramatically that in fact its wiring can be much less ‘hard’ than was once thought.

With the sparkling advances in the science of genetics it has become widely accepted that much of what ‘you’ are as a human being is preordained in your genes. Of course to a considerable extent this is true, but the pendulum has swung too far away from the idea of what ‘you’ can *become*.

In human evolution, the last part of the brain to develop was the frontal lobes, right behind the forehead, above the eyes. These make up more than 40 per cent of the brain’s volume. This is also the last area in the brain to connect up in the child – in fact, it really only wires up fully in the late teens or early twenties. It is this part of the brain that makes us truly human.

In the frontal lobes you hold an image of yourself, and it is according to this image that you go out to meet the world. How you behave in that world will depend on the frontal lobes regulating the older parts of the brain. In the frontal lobes you project yourself into a future and steer yourself through life by plans and goals set in that future. The electric ‘you’, born of love and experience, soothes your inherited biology, trimming its sails for the soft winds of human relationships and civilization.

It is in the frontal lobes that you conceive of the minds of other people, with all that that entails for morals, trust, faith and love. Without the frontal lobes, you are no longer ‘you’. Without the frontal lobes, there can be no conscience, will or civilized humanity. Of all the parts of the brain, the frontal lobes are the least hard-wired, the most adaptable to the world’s restless tugging and murmuring at our senses. The frontal lobes are evolution’s gift to us – or its curse. Here reside our self-awareness and our loss of innocence. We were cast out of the Garden of Eden when this part of the brain became fully evolved, for with it came choice, will and conscience.

We are unique because evolution has endowed us with the ability to shape our own destinies – and to shape our own brains. As a species, we have succeeded because of this 40 per cent of the brain with its capacity for near-infinite adaptability. So let’s cast off the notion that we are pre-programmed clusters of brain modules doomed to behave according to ancient plans while deluded by the notion that we act through free will! On the contrary: while much of our behaviour is genetically influenced, we can – through our civilization and culture – mould the human brain. In so doing we can have some escape from the shackles of biology.

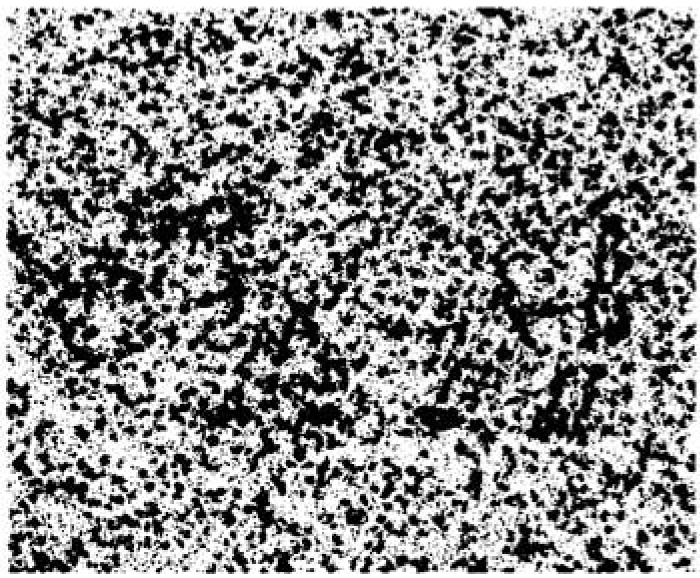
2
The Trembling Web

Take a moment to glance at the picture on *page 15**, then bring your eyes back here and read on. Do you recognize what the picture shows? Random dots? In a moment I will ask you to look again, but this time, when you are scanning the picture, try to be aware of your eyes as they search it for meaning. At the moment you scan the picture, your brain will send electrochemical impulses through chains of nerve cells to your eyes, commanding them back and forth across the page, trying to make sense of the pattern. As this happens, your eyes will be transmitting the patterns of the figure through the nerve cells to the vision centres at the back of your brain, just above the nape of your neck. From there, signals will be sent forward again through more and more advanced decoding centres of the brain's visual system.*

Now look at the picture again briefly, before bringing your eyes back to this line of print. Try to imagine this electrical to-ing and fro-ing along the bundles of long white fibres that connect the brain's nerve cells. If pick-ups were attached to your scalp at the moment of looking, the electrical activity would be displayed as a continuously moving wave on a screen. The microvoltage could even be amplified to light an electric bulb or move a toy electric train.

Now glance once more at the picture. What is it? Could you sense the brain's decoders trying to make guesses about what it is you were looking at? Could it be a flower?

A piece of furniture? Just above your ears – in the temporal cortex – the brain's centres for decoding and recognizing objects were working overtime trying to match the pattern of dots with real objects it has learned and stored in memory.



Each time your eyes moved to another position on the picture, a new set of signals passed from the eye, to the back of the brain and forward again to the decoders. New guesses were made, but they drew a blank. The eyes were instructed to move again, to search further for meaning. More electrical current, more brain activity – but the decoders still drew a blank.

Turn now to the picture on page 206 and glance at it before turning back here. You should have seen the picture of a rhinoceros. Now peep again at the picture opposite. Do you see the animal there that you didn't recognize before? You should see it now. If not, hold the book at arm's length. These dots should have form and meaning now. Neurones – brain cells – specialized for detecting objects are now firing in the temporal lobes of your brain. A few seconds ago the pictures were meaningless dots and the object-recognition brain cells were not reponding strongly. Now these cells *spark into life as they suddenly discern a meaning that was missing before.*

You have just changed your brain. A week from now, if you look at the same dotty puzzle, you will see the rhino in it because the object-recognition brain cells have been primed to fire to such images. They learned through just one fragment of experience – a glance at the picture on *page 206* *– which prepared them to fire. Thus readied, when the blobs reached them again these cells had a sort of 'ah-ha' experience and fired to the tiny clues almost hidden in the jumble of dots.*

This fragment of experience changed the connections between neurones in your brain. This was brain sculpture in action – the moulding like soft plastic of nerve tissue by the murmuring and flickering of the world on your senses. Thus a fragment of the energy present in the universe impinges upon you and changes you for ever. You, in turn, transform and return that energy to the universe in many ways: by what you say, do, think and feel; by the flickering millivoltages spreading at this very moment from your brain out into the cosmos.

The trembling web

Everything which makes up 'you' – memories and hopes, pain and pleasure, morals and malevolence – is embroidered in a trembling web of 100 billion brain cells. On average, each cell is connected 1,000 times with other neurones, making a total of 100,000 billion connections. There are more cell meeting-points in a human brain than there are stars in our galaxy.

A meeting-point between two cells is called a 'synapse' and was first described by the Oxford physiologist Sir Charles Sherrington at the turn of the century. A brain cell is shaped a bit like an onion, with a roundish middle, a single long shoot at one end and lots of thinner root-like fibres sticking out at the other. An onion sucks up nutrients from the ground, processes them in the onion bulb and sends the results up into the sprouting shoot. Brain cells work a bit like this.

The cluster of thin fibres converging on the brain cell corresponding to the onion's roots are called 'dendrites'. These, like the roots of the onion, suck nutrition into the brain cell. The particular 'nutrition' which they bring consists of electrochemical impulses from other brain cells. The tendrils from these other cells itch and nag at our cell's surface, trying to annoy it into action. Or at least some of them do: others try to nag the cell into 'silence' – to inhibit it.

Whether or not a brain cell fires therefore depends upon the final arithmetic of the combined hectoring of all these inputs – all the 'Go, go!' inputs minus all the 'Stop, stop!' inputs. Once this arithmetic exceeds a particular level, then the brain cell fires, sending an electrochemical impulse shooting up the equivalent of the onion's single green shoot.

This green shoot on the brain cell is called its 'axon'. A cell has a single axon, which is its only channel into the rest of the brain. Axons can range in length from a tenth of a millimetre to 2 metres! When the brain cell is coaxed into sending a signal up its axon, it does so in a single blurting pulse rather than in a constant trickle. This pulse lasts about a thousandth of a second and travels at a speed of anything between 2 and 200 miles per hour.

Having travelled up the axon, the pulse causes an itch at the point of contact with the dendrites of another brain cell. That point of contact is the synapse. This reaction continues through the trembling web of neurones, connected by synapses, and so a chain reaction occurs, with cells firing off in their hundreds, thousands or millions across the three-dimensional net. Some of these cells are triggered by the impulses reaching their dendrite roots, others are silenced and inhibited.

At this very moment, as you read this sentence, exactly this cascade of brain-cell firings is happening in your brain, across these all-important junctions – the synapses. At the beginning of the chapter, when you recognized the rhinoceros emerging out of the blobs, it was changes at the synapses in the object-recognition areas of your brain that made you see the familiar pattern of the animal. At first you didn't see the rhino because the dots were not clear enough to trigger activity in the brain cells which are specialized for recognizing objects. Shown a more recognizable object, however, these cells *did* spring into life.

The dots in the first figure did, of course, have some similarity to the face in the second picture and these similarities were strong enough to fire the object-decoding cells when you looked at the blobs again. So isn't this just the same as when you eat a piece of garlic and then for a while everything tastes of garlic? There's nothing very surprising about that. The object-recognition cells get some exercise by being shown the clear picture and so are just a bit more limbered up when given the blobs. What has this got to do with brain sculpture?

While there is certainly something in the garlic analogy, it is far from being the whole story. The rest of the story takes us to the brain's central trick – and this trick is the reason that our brains are such a wonderful medium for sculpture. We have seen that a brain cell fires when it gets enough of a push from the axons of other brain cells itching and nagging at its surface. When you saw the clear animal, this sent impulses cascading down thousands of dendrites into the cell. In response, the neurone spat a pulse up its axon, which in turn helped trigger another cell into action.

As all this happens, cells that don't have much to do with each other end up firing off at more or less the same time. This is not because they are close buddies, but simply because both happened to be triggered by the same cascade of activity in the brain – the surge of electrical activity generated by seeing the animal. It's a bit like being stuck in a delayed plane with someone: at first you don't have anything to do with the person beside you, but after an hour or two you will be groaning and complaining together. A similar thing happens to brain cells. After a few repetitions of firing together, they tend to team up. When two connected neurones have been triggered at the same time on several occasions, the cells and synapses between them change chemically so that when one now fires, it will be a stronger trigger to the other. In other words, they become partners and in future will fire off in tandem much more readily than before. This is called 'Hebbian learning', after the Canadian psychologist Donald Hebb, and the chemical change in cells and synapses is called 'long-term potentiation' (LTP).

In the case of the dotted figure you stared at earlier, only when the easy-to-recognize rhino had activated the relevant cells did they fire. Once this has happened a few times, however, the brain activity caused by the blobs becomes linked with the 'oh there's a …' action in the object-decoding cells. In other words, through Hebbian learning, the brain activity associated with the unclear dots becomes linked with the object-decoding cell activity.

Look at the unclear figure again. You see the animal easily now, probably, not everyone does. This is because the synapses between key neurones in your brain have been changed by the experience of seeing the clearer picture of the rhinoceros. So the very act of reading this chapter has remoulded connections between nerve cells in your brain. Whereas the term 'Hebbian learning' would have triggered no particular response in your brain before, these words will in future evoke some flicker of recognition.

As we live our lives, experience gradually remoulds us. Connections are made in the brain, and connections are broken. We learn and we forget. Anger transmutes to forgiveness, love to indifference, resignation to hope. You sign up for Spanish classes and embark on remoulding a few million synapses as you wrestle with the grammar, vocabulary and pronunciation. Then you become too busy to continue and the connections wither. Go to Spain on holiday next year, however, and you surprise yourself with what emerges from your lips as you relax over a glass of perfumed Rioja. Words and phrases you thought you had forgotten slip out. You even understand snatches of conversation between the two Spaniards at the next table. Traces of your evening classes have lingered in your brain, filigreed in the trembling web of connections between cells, and, just as the prince's kiss woke Sleeping Beauty, the sound of the Spanish language on your holiday has woken those dormant connections. There, in the synapses' chemistry, lingers the memory of the changes which experience and learning have wrought.

Some experience stamps itself on your brain so firmly that even dementia does not dislodge it. Alzheimer's Disease, in its last stages, can make you forget your loved ones and lose track of time, place and personality. Yet when Margaret Thatcher was British Prime Minister, it was common for Alzheimer's patients who could remember little else to be able to recognize her face and recall her name.

Nor do you forget the smell of new-baked bread from the bakery in the small French town where you had that wonderful holiday; the feeling of holding your child for the first time; the moment you heard some terrible news … Some experiences echo so widely and strongly through our brains that the changes they cause in the synapses will never be undone. This is particularly true when these events activate the emotional centres of the brain, for then the experience becomes woven into an even wider fabric of nerve tissue – and is hence much less easily unravelled.

Experience, in short, is sculpted into the *pattern* of connections between neurones, not necessarily into specific connections between particular pairs of neurones. This is not only good news but is also utterly essential for our survival, as our brain connections are in flux throughout our life. If all our experience, memories and personality depended on very specific connections between particular neurones, then memory and personality would degrade far more dramatically and unpredictably than they actually do under normal circumstances. This brings us on to the subject of dance and death.

The death of cells and the synaptic dance

The connections between cells are constantly changing. In certain parts of the brain with particularly rapidly changing connections, it has been estimated that the average life of any one synaptic connection may be as short as eight hours. Neurones have been filmed, showing a continual, restless flux in their connections with other neurones.

It is just as well, therefore, that our sculptured brains do not lose their shape when some synapses disappear: if they did, we would all be like newborn babies, having to relearn each day the basics of living. In principle, however, the way the brain functions is little different from the way in which human organizations – companies, clubs or universities – work. These social groupings do not – unless they are very badly organized – collapse if a particular individual becomes sick or leaves. If an individual – even a very senior person – does go, the organization continues doing its job. It goes on because what it does is defined largely by the *relationships* between the employees, and these exist through roles and rules. Hence if the bookkeeper runs off with the postroom supervisor, the organization will not grind to a halt. Other employees can be drafted in to help out in these roles. To the outsider, the organization will continue working as if nothing had happened.

So it is in your brain. Today the connections between brain cells will change, yet tomorrow your family and workmates will not notice anything different about you. This is because the billions of connections which make you 'you' preserve the *patterns* which store your experience and memory, even when some of the individual connections in these patterns disappear.

That is one of the key principles behind this book: the whole is more than the sum of its parts. And the whole can survive when some of the parts disappear. But why is there such restlessness in the synapses? Why are they continually in flux, touching, letting go, touching again? That brings us to our second key principle.

Cells that fire together, wire together

Does 'Hebbian learning' ring any bells for you? If so, it is because reading this book has moulded the synapses in the language centres of your brain so that these words now have some sort of meaning – no matter how vague or confused – linked to them. As we saw a few pages back, when several brain cells are triggered at roughly the same time, they team up. The synapses linking these cells develop a sort of hair-trigger, so that when one fires, they all tend to fire.

This neural trade unionism is one major reason for the restless ebbing and flowing of the brain's connections. Every second of every day, you experience events which trigger different sets of neurones in your brain. The billboard you glimpse on your way to work shows a car driven by a beautiful woman racing through a brush fire in an exotic, tropical location. These images fire off neurones in the emotional centres of your brain. At the same moment, the language and visual neurones of your brain register the logo and brand name of the car. Bingo! Two sets of neurones in distinct areas of the brain are switched on at the same time. Pass that billboard every morning for a few weeks, see similar images on television in the evening, and you have a complex of interconnected neurones wired together because they fired together. And what happens? You see the car in a showroom window and some fragment of the emotion which has been connected to it gets triggered – or so the marketing team hopes!

Advertising agents spend their lives trying to mould your synapses through Hebbian learning. Their constant battle is to try to link the products they are pushing with emotional circuits in the brain. Such methods are so successful in sculpting brains that regulatory codes for advertisers have had to be imposed. For instance, one such code in the UK forbids alcohol advertisers from using sexual images. However, linking anything with the sexual circuits of the brain through Hebbian learning is so effective in boosting sales that advertisers sail very close to the wind with, and at times flout, this regulation.

Marketing men and women want to link their products to the neurones in the emotional centres of your brain because such synaptic connections are much harder to dissolve than connections between other sets of neurones. Just try to remember what you learned in that Spanish class for confirmation of this!

Binding the body in the brain

Take a moment to look at the back of your left hand. Now take the forefinger of your right hand and slowly stroke the back of the left hand's middle finger. Close your eyes and do that several times, noticing the sensations in the middle finger.

Even with your eyes closed, there is no doubt which finger is being touched. As your forefinger moves down its length, the light pressure on each part of the finger triggers a separate set of neurones. It is the fact that each part of your finger is uniquely wired to a particular set of neurones in the brain that allows you to know where on your middle finger the touch is.

In fact, the whole surface of your body is precisely mapped on to a thin strip of tissue on the outer surface of your brain (the cortex). Known as the 'somato-sensory strip', it runs from approximately halfway along the top of your head down to just above each ear.

When your middle finger is touched, sensory neurones fire, sending electrochemical impulses up your arm and into the back of the spinal cord. The current passes along thin white nerve fibres – the axons – until it reaches the first synapse in the spinal cord. The electrochemical discharge caused by the touch then triggers the synapse in the spinal cord, which in turn fires. Its discharge travels up the spine through the long, uninterrupted, gossamer-thin axons, until it reaches a second synapse at the lowest part of your brain – the 'medulla'.

The incoming current arriving at this tiny synaptic canyon fires the neurone across to the other side of the valley. This is only the second such synapse that the touch-induced current has had to cross in the long journey between your left hand and the outer boundaries of your brain. The nerve fibres now cross to the right side of the brain.

The third stretch of axonal thread travels up from the very bottom of your brain, to a message-centre structure deep in the middle of the brain called the ‘thalamus’. Here your touch-current reaches its third synapse, in the right half of the thalamus. The message jumps the synaptic hurdle and finishes the last leg of its journey – the few centimetres between the thalamus and the somato-sensory strip on the cortex.

Because sensation on the right side of the body is registered on the left side of the brain, it was the right cortex that detected the touch on your left middle finger. Remember too that in its travels between your hand and brain, the electrochemical current crossed only three synapses.

Now another small exercise. Close your eyes again and run the forefinger of your right hand down your cheek. As you do so, try to pay attention to the fine sensations over the part of your face touched by the finger. Now, still with your eyes closed, run your finger down your calf. Again, be aware of the feelings in the touched skin.

How did the two sensations compare? You should have felt a much more delicate and precise sensation in your face than in your calf. One reason for this is that the number of brain cells devoted to each square centimetre of face is greater than for the calf.

The whole surface of the body is connected to the brain in an orderly fashion, with a so-called one-to-one mapping. In other words, all the fibres from the hand cluster together on the somato-sensory strip on the brain surface, and indeed each finger has its own block-booked season ticket of neurones clustered together on the cortex. Even the 5–6-foot wires from toe to brain finally hug together at the cortex, like refugees reunited after a long journey. There is no democracy for the refugees, however. The big hitters – face, hands, genitals – get allocated far more brain space than humbler parts of the body such as feet, legs and chest. One could blame corrupt immigration officials, but evolutionary pressure probably has more to do with it.

On the sensory strip, however, the different areas of the body are arranged in a slightly peculiar way. For instance, the hand season-ticket holders sit next to the face season-ticket holders in the stadium. This can have ghostly consequences if you lose part of your body – more of this later.

So, there we have it. Our nerve cells have wired up by the time we are toddlers and, like small-town accountants with loyal customers, the sensory cortex cells settle securely into a lifetime of blameless service to their client body part. Or do they?

As privileged members of the body, each finger has a big chunk of brain tissue at its disposal. There is, however, a rare congenital disorder known as 'webbed-finger syndrome', or 'syndactyly'. Some people are born with a hand which is more like a fist: though you can discern the outlines of fingers, they are webbed together so that they never move independently, but always together as a group.

What does the sensory map of the brain look like for the hands of these individuals? Well, the answer is that the brain space allocated to one finger is pretty well merged into the space devoted to another. In other words, the brain hasn't bothered to treat the fingers as individuals but deals with them largely as a single group, allocating one chunk of brain space to the whole hand.

Why is this? Maybe the same congenital factors that caused the webbed hand were also responsible for the unusual brain organization? Perhaps – but there is one dramatic way to test this. Surgeons have developed techniques for separating the webbed fingers so that they can be moved independently. When this happens, what happens to the brain? If the brain organization is set in stone by genetic factors, then nothing should happen.

Well, something quite dramatic does happen. Before surgery, the fingers have a single blob of cortex allocated to them *en masse*. Less than a month after surgery, however, the brain has given each finger its own personal patch of neurones. In short, brain organization has altered because the shape of the hand has changed.

Why? Remember the slogan of this section: ‘cells that fire together, wire together’. When the fingers of the hand were joined up, each time one finger moved, every other finger also moved. On the principle of Hebbian learning, this meant that the neurones responding to these individual fingers became synaptically connected with each other. In other words, when one fired, they all tended to fire.

When a group of neurones all fire in response to different stimuli, then the brain can’t distinguish these different stimuli. If, for instance, the neurones responding to different types of fruit all joined together in a Hebbian fashion in your brain, then you would lose the ability to distinguish a banana from a plum. Each would register in your brain as being much the same thing.

So it was for the fingers of the webbed hand. It was as if the block-booked season tickets in the stadium for four different groups of fans had become mixed up. When the fingers were surgically separated, however, the ‘fire together, wire together’ rule began to break down. When the forefinger moved, the little finger did not necessarily move with it. As a result, the synaptic connections between the areas representing the two fingers began to weaken, so that when one set was triggered the other set did not necessarily fire in solidarity. In consequence, each finger developed a more independent and specialized region of the brain.

We know now, therefore, that in the normal hand and brain each finger has its own neat allocation of neurones. This is in part because the brain cells representing each finger have become wired together through continually firing together in infancy. If this is true, then it would follow that if your mother had forced you to wear tight-fitting mitts for a long time, your brain would have developed a mitt-shaped map of your hand, without giving separate cells to separate fingers.

Indeed the brain can be trained in this kind of way to change its maps of the body surface. In one American study, for instance, monkeys were given harmless vibrating stimulation *across* the fingers over a long period. For many thousands of trials, the tip of each finger was touched at the same time by a vibrating bar. In normal life, the brain cells representing one finger all tend to fire together as that finger moves and touches something, but now, artificially, the brain cells for equivalent segments of *different* fingers were made to fire together again and again by the vibrating bar. The result was that the neurones representing the tips of each finger merged together in a Hebbian way. In effect, this meant creating in the brain a new *horizontal* finger across the hand – as well as, of course, 'dissolving' the old fingers! This happened because these neurones fired together repeatedly over a long period.

These maps, however, could easily be returned to normal after the training ended. As soon as the fingers stopped always getting the same horizontal touch at the same time, then normal stimulation of the fingers resumed. With each finger tending to move individually, this meant returning to the old situation where brain cells on the same finger were usually triggered together. This is brain sculpture in action, with neurones rewiring in line with experiences provided by the outside world.

Suppose one brain cell is made to fire by a touch on the skin. Then suppose that another cell close by which is *not* switched on by that outside trigger is made to fire repeatedly at the same time. Then, according to Hebbian learning, these two cells should become wired up together. Now, the touch-neutral cell should begin to fire when the skin is touched, because it has teamed up with the other touch-sensitive cell.

This is fine in theory, but how can you contrive to make cells fire together in this way? Well, one way is to stimulate the surface of the brain with tiny electric currents. When you do this, you trigger a whole bunch of cells into firing together, even though they might not normally do so in response to stimulation from the outside world. If you do this for long enough – over several hours in fact – sure enough, you find that you have created new sensory body maps in the stimulated part of the brain.

You changed your brain by looking at the rhinoceros picture at the beginning of this chapter. Thoughts and experience change the way your brain is wired up, but so can passing tiny electrical currents through your brain. These two totally different methods for changing the brain are, however, based on the one principle – Hebbian learning.

When cells fire apart, wires depart

As we have seen, the monkeys whose fingers had been stimulated, so changing their finger brain maps, didn't stay permanently altered by the experience: the artificial horizontal finger maps in the brain quickly dissolved once the monkeys resumed normal life. Holiday romances and