The appendix notes from...

SEVEN AND A HALF LESSONS ABOUT THE BRAIN

Lisa Feldman Barrett

Houghton Mifflin Harcourt
Boston New York
2020

hmhbooks.com

Library of Congress Cataloging-in-Publication Data
Names: Barrett, Lisa Feldman, author.
Title: Seven and a half lessons about the brain / Lisa Feldman Barrett.
Description: Boston : Houghton Mifflin Harcourt, 2020. |
Includes bibliographical references and index. | Summary: "From the author of How Emotions Are Made, a myth-busting primer on the brain, in the tradition of Seven Brief Lessons on Physics and Astrophysics for People in a Hurry"—Provided by publisher.
Identifiers: LCCN 2020023431 (print) | LCCN 2020023432 (ebook) |
ISBN 9780358157144 (hardcover) | ISBN 9780358157120 (ebook)
Subjects: LCSH: Brain—Popular works. | Neurosciences—Popular works.
Classification: LCC QP376 .B357 2020 (print) | LCC QP376 (ebook) |
DDC 612.8/2—dc23
LC record available at https://lccn.loc.gov/2020023431
LC ebook record available at https://lccn.loc.gov/2020023432

Book design by Emily Snyder

Printed in the United States of America
DOC 10 9 8 7 6 5 4 3 2 1

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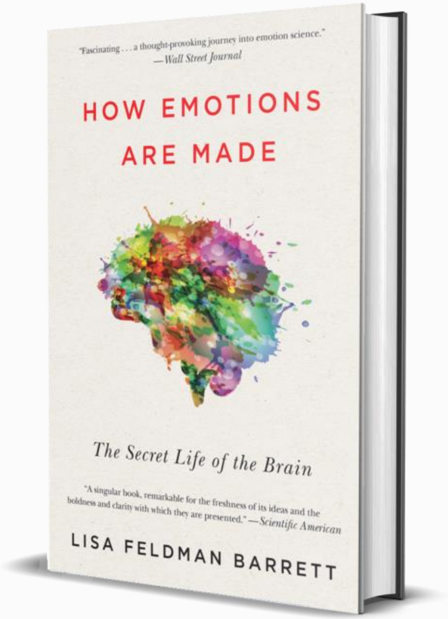

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SEVEN
AND A HALF
LESSONS
ABOUT THE
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Appendix notes for the audiobook

Notes by page

Approximate time in audiobook

00:30

The Half-Lesson: Your Brain Is Not for Thinking

1 *Amphioxi populated the oceans about 550 million years ago:* These ancient creatures, also called lancelets, are still around today. Amphioxi are our evolutionary cousins in the following way: Humans are vertebrates, meaning that we possess a backbone, which we call a spine, and a nerve cord, which we call a spinal cord. Amphioxi are not vertebrates, but they have a nerve cord running stem to stern. They also have a backbone of sorts, called a notochord, made of a fibrous material and muscle instead of bone. Amphioxi and vertebrates belong to a larger group of animals known as chordates (phylum Chordata), and we share a common ancestor. (More on this ancestor shortly.)

Amphioxi lack all sorts of features that distinguish vertebrates from invertebrates. They have no heart, liver, pancreas, or kidneys, nor the internal bodily systems that go with these organs. They do have some cells that regulate a circadian rhythm and produce a cycle of sleeping and waking.

Amphioxi do not have a distinct head or any of the visible sense organs that are found in a vertebrate head, such as eyes, ears, a nose, and so on. At its most anterior tip, an amphioxus has a small group of cells on one side, called an eyespot. These cells are photosensitive and can detect gross changes in light and dark, so if a shadow falls on the animal, the animal moves away. The cells of this eyespot share some genes in common with a vertebrate retina, but amphioxi do not have eyes and cannot see.

Also, amphioxi cannot smell or taste. They have some cells in their skin to detect chemicals in the water, and these cells contain some genes that are similar to those found in a vertebrate olfactory bulb, but it is not clear that the genes function in the same way. An amphioxus also has a cluster of cells with hairs in them that enable it to orient and balance its body in water and perhaps sense acceleration when it swims, but amphioxi do not have inner ears with hair cells to hear with, as vertebrates do.

Amphioxi also cannot locate food and approach it; they dine on whatever stream of little creatures the ocean currents deliver. They have cells to detect the *absence* of food and wriggle away in a random direction that hopefully will lead to a meal (in effect, the cells signal, *Anyplace is better than here*). See 7half.info/amphioxus.

01:13 1 *a teeny clump of cells that was not quite a brain:* Scientists continue to debate whether amphioxi have brains. It all comes down to where you draw the dividing line between "brain" and "not a brain." The evolutionary biologist Henry Gee sums up the situation well: "Nothing like the vertebrate brain is seen in either tunicates [sea squirts] or the amphioxus, although there are traces of its ground plan . . . if one looks hard enough."

Scientists pretty much agree that a sketch of the genetic outlines of the vertebrate brain can be found in anterior end of the amphioxus notochord, and these outlines are at least 550 million years old. This does not necessarily mean that the genes found in the anterior end of the notochord work in the same way or produce the same structures that they do in the brain of a vertebrate. (For more details on what it means for two species to have similar genes, see the appendix entry for lesson no. 1, "reptiles and nonhuman mammals have the same kinds of neurons that humans do.") And this is where the scientific debates begin. Amphioxi have some of the molecular patterns that organize the vertebrate brain into major segments, but scientists debate which segments are sketched out and which segment instructions are absent. It is also debatable whether the actual segments are present in amphioxi. Similarly, an amphioxus has the rudimentary genetic foundations necessary for a head, even though it has no head per se.

For a more detailed discussion of amphioxi, see Henry Gee's *Across the Bridge: Understanding the Origin of the Vertebrates,* and the evolutionary neuroscientists Georg Striedter and Glenn Northcutt's book *Brains Through Time: A Natural History of Vertebrates.* See 7half.info/amphioxus-brain.

01:32 2 *you behold a creature very similar to your own ancient, tiny ancestor:* Scientists believe that our common ancestor with amphioxi resembled modern amphioxi very closely, because amphioxi's environment (their niche) has barely changed in the past 550 million years, so they wouldn't have had to adapt much. In contrast, vertebrates have undergone tremendous evolutionary changes, as have other chordates, such as sea squirts. Therefore, scientists assume that by studying modern amphioxi, we can learn about the common ancestor of all chordates.

Still, some scientists continue to debate these assumptions—it's unlikely that amphioxi have not changed *at all* in half a billion years! For example, the amphioxus notochord (its central nervous system) extends the entire length of its body, from tip to tail, whereas in vertebrates, the spinal cord ends where the brain begins. Scientists debate whether our shared ancestor had an amphioxus-like notochord that became shorter in conjunction with evolving a vertebrate brain, or a shorter notochord that extended during evolution. Several similar debates (e.g., the evolution of olfaction) exist as well.

For a more detailed discussion of our amphioxus-like ancient ancestor, see Henry Gee's *Across the Bridge*. See 7half.info/ancestor.

02:44

2 *Why did a brain like yours evolve:* Statements like "Your brain is for *this*" and "Your brain evolved to do *that*" are examples of teleology, from the Greek word *telos*, meaning "end," "purpose," or "goal." Several types of teleology are discussed in science and philosophy. The most common type, which is generally discouraged by scientists and philosophers, is a statement that something was *intentionally designed for a purpose with an ultimate end point*. An example is suggesting that brains evolved in some kind of upward progression—say, from instinctual to rational, or from lower animals to higher animals. That is not the form of teleology I'm using in this lesson.

A second type of teleology, which I have employed in this lesson, is a statement that something is a *process that embodies a goal with no ultimate end point*. In stating that the brain is not for thinking but for regulating a body in a particular niche, I am not implying that body budgeting—allostasis—has some final end state. Allostasis is a process that anticipates and deals with ever-changing environmental input. All brains manage allostasis. There's no orderly progression from a worse way to a better way.

The psychologists Bethany Ojalehto, Sandra R. Waxman, and Douglas L. Medin study how people across cultures reason about the natural world. Their research suggests that teleological statements of the sort employed in this lesson reflect an appreciation of the relationships among living things and their environments. They call it "contextual, relational cognition." A statement like "A brain is not for thinking" is inherently relational (it refers to the relationship among the brain, various bodily systems, and stuff in the environment) and does not reflect that the brain was intentionally designed for a purpose with a final end point.

My phrasing (e.g., "Your brain is not for thinking") also appears in a particular context—in a nontechnical essay that describes aspects of brain function. The phrasing achieves its full meaning only in the context in which it's employed. If you strip away the context, it's easy to mistake the statement as the first, problematic type of teleology. Allostasis is of course not the sole cause of brain evolution and did not drive evolution in some orderly fashion. Brain evolution was largely driven by natural selection, which is haphazard and opportunistic. Brain evolution may also be influenced by cultural evolution, which I discuss in lesson no. 7. See 7half.info/teleology.

8 *The scientific name for body budgeting is* allostasis: Allostasis is not the only factor influencing how brains evolve and how they work, but it's a big one. Allostasis is a predictive balancing process over time, not a process that seeks a single, stable point for the body to maintain (it's not like a thermostat). The word for seeking a single, stable point is *homeostasis*. See 7half.info/allostasis.

11:13 8 *The movement should be* worth the effort, *economically speaking:* The idea of worthwhile movement is well studied in the field of economics, where it's called *value*. See 7half.info/value.

12:02 9 *the insides of bodies became more sophisticated:* The organs inside your body, such as your heart, stomach, and lungs, are called *viscera*, and they are part of broader visceral systems below your neck, such as your cardiovascular system, your gastrointestinal system, and your respiratory system, respectively. Movements that happen inside your heart, gut, lungs, and other organs are called *visceromotor* movements. Your brain controls your visceral systems (i.e., it performs visceromotor control). In the same way that your brain has a primary motor cortex and a whole system of structures in your subcortex for controlling your muscle movements, it also has a primary visceromotor cortex and a whole system of subcortical structures for controlling your viscera. Some visceral organs, like your lungs, require your brain in order to function. Your heart and your gut, however, have their own intrinsic rhythms, and the visceromotor system in your brain fine-tunes them. One last note: your body has other systems not typically linked to any visceral organ, such as the immune system and endocrine system, and their changes are also broadly referred to as visceromotor.

In the same way that the motor movements of your arms, legs, head, and torso produce sense data that is relayed to your brain (specifically, to the somatosensory system), visceromotor movements produce sensory changes, called *interoceptive* sense data, that are sent to your brain (to the interoceptive system). All this sense data helps your brain better control your motor and visceromotor movements.

The best scientific estimates today suggest that the evolution of visceral and visceromotor systems in vertebrates was accompanied by the evolution of sensory systems. After conception, when an embryo is building its brain and body, the visceral systems and the sensory systems both emerge from the same temporary cluster of cells, called the neural crest. So does the segment of the vertebrate brain that contains the visceromotor and interoceptive systems, which is known as the forebrain. The neural crest is unique to vertebrates and can be seen in all vertebrate species, including humans.

Visceromotor and interoceptive systems play a key role in determining the value of any movement, but we cannot say they evolved for that reason. Other selection pressures contributed to the evolution of the body's visceral systems and the brain's visceromotor system, such as the evolution of larger bodies that needed new kinds of tending and maintenance. For example, most animals on this planet are small in diameter, with only a few cells that span from the inside of the body to the outside world. This arrangement makes certain physiological functions easier, like the exchange of gases (in breathing) and removal of waste products. In a larger body, the inside of the body is farther away from the outside world, so new systems have evolved, like one that pumps water over gills to facilitate gas exchange, and the kidneys and an extended gut to excrete waste. These new systems allowed vertebrates to become more powerful swimmers and, accordingly, more successful predators. See 7half.info/visceral.

Lesson 1. You Have One Brain (Not Three)

00:20

13 *Your human mind, wrote Plato:* Plato wrote about the *psyche*, which differs from our modern idea of a mind. I am following the colloquial tradition of using *psyche* and *mind* as synonyms. See 7half.info/plato.

01:27

14 *scientists later mapped Plato's battle onto the brain:* The triune brain idea fused neuroscience with Plato's writings about the human psyche. In the early twentieth century, the physiologist Walter Cannon proposed that emotions were triggered and expressed (respectively) by two brain regions, the thalamus and the hypothalamus, which sit directly beneath the supposedly rational cortex. (Today, we know that the thalamus is the main gateway for all sense data, except for chemicals that become smells, to reach the cortex. The hypothalamus is critical for regulating blood pressure, heart rate, respiratory rate, sweating, and other physiological changes.) In the 1930s, the neuroanatomist James Papez proposed a "cortical circuit" dedicated to emotion. His circuit went beyond the thalamus and hypothalamus to include cortical regions that border the subcortical regions (the cingulate cortex) and were therefore assumed to be ancient. This segment of cortex was dubbed the limbic lobe by the neurologist Paul Broca fifty years earlier. (He used the term *limbic*, which comes from the Latin word meaning "border," *limbus*. This tissue abuts the brain's sensory systems and the motor system that moves your arms, legs, and other body parts. Broca thought the limbic lobe housed primitive survival faculties, like the sense of smell.) In the late 1940s, the neuroscientist Paul MacLean transformed Papez's "corti-

cal circuit" into a full-fledged limbic system and embedded it within a three-layered brain that he named the *triune brain*. See 7half.info/triune.

02:54 *The outermost layer, part of the cerebral cortex:* The many brain terms that include *cortex* can be confusing. The cerebral cortex is a sheet of neurons arranged in layers that covers the subcortical (meaning "below the cortex") parts of your brain. It is popularly believed that one part of the cerebral cortex is evolutionarily old and belongs to the limbic system (e.g., the cingulate cortex) and another part is evolutionarily new, which is why it's called the neocortex. This distinction derives from a misunderstanding of how the cortex evolved, which is the topic of this lesson.

04:21 15 *one of the most successful and widespread errors in all of science:* Scientists normally try to avoid saying that something is a fact or is definitively true or false. In the real world, facts have some probability of being true or false in a particular context. (As Henry Gee says in his book *The Accidental Species: Misunderstandings of Human Evolution*, science is a process of quantifying doubt.) In the case of the triune brain, however, it's justified to use more absolute language. By the time MacLean published his magnum opus, in 1990, *The Triune Brain in Evolution: Role in Paleocerebral Functions*, the evidence was already clear that the triune brain idea was wrong. Its continued popularity is an example of ideology rather than scientific inquiry. Scientists work hard to avoid ideology, but we are also people, and people are sometimes guided by belief more than data. (See Richard Lewontin's book

Biology as Ideology: The Doctrine of DNA.) Mistakes are part of the normal process of science, and when scientists acknowledge them, they are great opportunities for discovery. Learn more in Stuart Firestein's books *Failure: Why Science Is So Successful* and *Ignorance: How It Drives Science*. See 7half.info/triune-wrong.

09:16 18 *genes were most likely present in our last common ancestor:* This assumption depends on there not having been much evolutionary change in the cells of animals we're comparing.

More generally, genes are not the whole story when it comes to inferring whether two animals have brain features that can be traced back to a common ancestor even when those features look different to the naked eye. Sometimes genes can be misleading. And some scientists use other sources of biological information, such as the connections between neurons, to determine whether two brain structures have a common ancestry. For a more detailed discussion of this topic, which is called homology, see Georg Striedter's *Principles of Brain Evolution* and Striedter and Northcutt's *Brains Through Time*. See 7half.info/homology.

09:43 *as brains become larger over evolutionary time, they reorganize:* This idea comes from the neurobiologist Georg Striedter. He likened brains to companies, which reorganize to scale up their business. See Striedter's *Principles of Brain Evolution*. It is also possible for brains to lose complexity over evolutionary time or during development; an example is tunicates (sea squirts). See 7half.info/reorg.

11:30 19 *segregating and then integrating:* Here is an analogy to reinforce my comparison of the primary somatosensory cortex in rats and humans. The author and chef Thomas Keller explains that if you cook a bunch of vegetables together in a pot, the mixture will have a single, blended flavor. No individual ingredient stands out. But, Keller explains, there's a better, tastier way to make your dish: cook each vegetable separately and assemble them in the pot at the end. Now every spoonful is a different complex medley of flavors. The difference between these two techniques is essentially the difference between the primary somatosensory cortex in rats and humans. The rat's single region is like a single pot containing all the ingredients, and the four human regions are like four pots with separate ingredients. In the language of lesson no. 2, the four-pot technique has higher complexity. See 7half.info/keller.

12:22 *reptiles and nonhuman mammals have the same kinds of neurons that humans do:* By this, I mean the neurons have the same molecular identity—a specific gene or sequence of genes—that performs the same genetic activities (e.g., they make the same proteins). A given gene does not necessarily make the same proteins in every animal where it's found. Two animals can have the same genes, but those genes can function differently or produce different structures. And even within the same animal, a network of genes can perform different genetic activities at different times in development. (For a clear explanation and examples, see Henry Gee's book *Across the Bridge*.) The important observation here is that two creatures can have neurons with some of the same genes that function the same way in both creatures, and yet those neurons can differ in how they are organized, resulting in very different-looking brains. See 7half.info/same-neurons.

13:15 21 *The common brain-manufacturing plan:* This research originated with evolutionary and developmental neuroscientist Barbara Finlay, who calls it the "translating time" model. Finlay built a mathematical model that predicts the timing of 271 events in developing animal brains. Some of these events include when neurons are created, when axons begin to grow, when connectivity is established and refined, when myelin starts to form over the axons, and when brain volume starts to change and expand. Finlay's model calculates the equivalent number of days for any developmental event across eighteen mammalian species that have been studied and even some animal species not included in the original model. If one compares her model's predicted timing to the actual timing of brain formation, the correlation is an astounding 0.993 (on a scale of -1.0 to 1.0). This means the ordering of events is close to identical for all species studied, because they're all described by a single model.

Additionally, the genes found in various mammalian brain cells provide molecular genetic evidence that is consistent with the translating time model. The brain cells of jawed fish contain those genes as well. Some genes go all the way back to amphioxus and very likely to its common ancestor with humans. So, based on the genetic evidence alone, it's reasonable to infer that the common manufacturing plan (or part of it) holds for all jawed vertebrates. See 7half.info/manufacture.

15:12 22 *the human brain has no new parts:* As a neuroscientist, I am persuaded by the evidence that supports Finlay's hypothesis of a common brain-manufacturing plan. Interested readers should be aware, however, that some scientists continue to hold to the idea that certain features of the human brain, such as the prefrontal cortex, have evolved to become larger than expected for a scaled-up primate brain. My view is that some of the distinctive capacities of a human brain come from a combination of a big cerebral cortex (not bigger than expected for the overall brain size, mind you, just big in absolute terms) and souped-up connections between neurons in certain parts of the cortex, including upper layers of the prefrontal cortex. Some scientists, myself included, hypothesize that these features give humans the ability to understand things by their function rather than their physical form, as I discuss in lesson no. 7 and in my earlier book, *How Emotions Are Made: The Secret Life of the Brain*. See 7half.info/parts.

19:04 24 *There is no such thing as a limbic system dedicated to emotions:* Even though the limbic system is a myth, your brain does contain something called limbic circuitry. Neurons in limbic circuitry connect to the brain stem nuclei that regulate your autonomic nervous system, immune system, endocrine system, and other systems whose sense data create interoception, your brain's representation of the sensations in your body. Limbic circuitry is not exclusive to emotion and is distributed across multiple brain systems. It includes subcortical structures, such as the hypothalamus and the central nucleus of the amygdala;

allocortical structures, such as the hippocampus and the olfactory bulb; and parts of the cerebral cortex, such as the cingulate cortex and the anterior part of the insula. See 7half.info/limbic.

19:50 24 *The triune brain idea and its epic battle between emotion, instinct, and rationality is a modern myth:* The triune brain belongs to a long history of entrenched myths in science. Here are some more to amuse you. In the eighteenth century, serious scholars believed that heat was created by a mythical fluid called caloric and that combustion was caused by an imaginary substance called phlogiston. Physicists of the nineteenth century insisted that the universe was filled with an invisible substance called luminiferous ether that permitted light waves to propagate. Their medical colleagues attributed illnesses such as the plague to smelly vapors called miasmas. Each of these myths survived and substituted for scientific fact for one hundred years or more before it was overturned. See 7half.info/myths.

21:08 25 *we're just an interesting sort of animal:* This idea comes from Henry Gee's book *The Accidental Species.* See 7half.info/interesting.

Lesson 2. Your Brain Is a Network

02:58 30 *Your brain is a* network: Your brain network is made of smaller networks, or subnetworks, of interconnected neurons. Each subnetwork is a loose collection of neurons that constantly join in and leave as the subnetwork functions. Think of a basketball team that has twelve to fifteen players but only five of them participate at a time. Players switch in and out of the game, but we still view the people on the court as the same team. Likewise, a subnetwork is maintained even though the actual neurons that create it switch in and out. This variability is an example of degeneracy, when structurally dissimilar elements (such as groups of neurons) perform the same function. See 7half.info/network.

03:29 31 *a network of 128 billion neurons:* My count of 128 billion neurons in the average human brain is higher than you may find in other sources, which commonly cite about 85 billion neurons. The difference is due to the fact that neurons can be counted by different methods. In general, scientists estimate the number of neurons in a brain using stereological methods, which employ probability and statistics to estimate the three-dimensional structure of neurons from two-dimensional images of brain tissue. The 128 billion figure comes from a paper that used a stereological method called optical fractionator that counted about 19 billion neurons in the human cerebrum, including the cerebral cortex, the hippocampus, and the olfactory bulb, and another 109 billion or so granule cells in the cerebellum, plus 28 million or so Purkinje neurons in the cerebellum. The more common figure of 85 billion neurons comes from another method called isotropic fractionator, which is simpler and quicker but systematically omits some neurons. See 7half.info/neurons.

03:39 *A brain network is not a metaphor:* The brain isn't symbolically *like* a network—it really *is* a network, meaning it functions similarly to other networks. The term *network* is a concept here, not a metaphor. It helps call to mind other networks that you know to help you understand better what a brain network is and how it works.

04:12

31 *Generally speaking, each neuron looks like a little tree:* The human brain has different types of neurons of various shapes and sizes. The kind of neuron I've described in our lesson is a pyramidal neuron in the cerebral cortex.

05:28

33 *I'll refer to this whole arrangement as the "wiring" of your brain:* The simple term *wiring*, as I use it, stands in for more specific structural details. In general, a neuron consists of a cell body, some branch-like structures on the top called dendrites (think the crown of a tree), and one long, slender projection with a root-like structure on the bottom called an axon. Each axon is much thinner than a human hair and has little balls on the end, called axon terminals, that are filled with chemicals. Dendrites are riddled with receptors to receive the chemicals. Typically, the axon terminals of one neuron are close to the dendrites of thousands of other neurons, but they do not touch, and the intervening spaces are called synapses. When a neuron's dendrites detect the presence of chemicals, the neuron "fires" by sending an electrical signal down its axon to its axon terminals, which release their neurotransmitters into the synapses; the neurotransmitters then attach to receptors on the other neurons' dendrites. (Other cells, called glial cells, help the process along and prevent chemical leaks.) This is how neurochemicals excite or inhibit the receiving neurons and change their rate of firing. Through this process, one individual neuron influences

thousands of others, and thousands of neurons can influence one, all simultaneously. This is the brain in action. See 7half.info/wiring.

13:20 37 *the area is routinely called the visual cortex:* What does it mean to "see"? Your conscious experience of things in the world, like seeing your hand or your phone, is created in part by neurons in your occipital cortex. It is possible to navigate the world if these neurons are damaged, however. If you place an obstacle in front of a person with damage to the primary visual cortex, the person won't consciously see the obstacle but will walk around it. This phenomenon is called blindsight. See 7half.info/blindsight.

13:32 *if you blindfold people with typical vision:* The study of blindfolded people who learned braille is another demonstration that neurons have multiple functions. When the scientists disrupted neural firing in the primary visual cortex (V1) using a technique called transcranial magnetic stimulation, blindfolded test subjects had a harder time reading braille, although that difficulty disappeared twenty-four hours after the blindfold was removed and visual input was available again to be processed by V1. See 7half.info/blindfold.

19:57 41 *A system has higher or lower complexity:* Complexity does not imply an orderly progression of brains on some phylogenetic scale or *scala naturae* from less complex to ever more complex, culminating in the human brain. The brains of other animals, such as monkeys and worms, also have complexity. See 7half.info/complexity.

21:27 41 *Meatloaf Brain:* I drew inspiration for this name from the book *The Blank Slate* by psychologist Steven Pinker; in it, he described a "uniform meatloaf" mind as "a homogeneous orb invested with unitary powers." See 7half.info/meatloaf.

22:10 42 *Pocketknife Brain:* This name was inspired by evolutionary psychologists Leda Cosmides and John Tooby, who described a human mind as like a Swiss Army knife. See 7half.info/pocketknife.

22:27 *A real pocketknife with, say, fourteen tools:* Here's a bit more mathematical detail behind the complexity of a fourteen-tool pocketknife. In a particular configuration of the pocketknife's tools, which I've called a pattern, each tool has two possible states: used or unused. Fourteen tools with two states each yields about 16,000 possible patterns for the whole pocketknife:

$$2\times2\times2\times2\times2\times2\times2\times2\times2\times2\times2\times2\times2\times2=2^{14}=16{,}384$$

Adding a fifteenth tool doubles the number of patterns:

$$2\times2\times2\times2\times2\times2\times2\times2\times2\times2\times2\times2\times2\times2\times2=2^{15}=32{,}768$$

If each tool is given an additional function, it now has three possible states instead of two—its first function, its second function, or unused. This yields far more total patterns for the pocketknife:

$$3\times3\times3\times3\times3\times3\times3\times3\times3\times3\times3\times3\times3\times3=3^{14}=4{,}782{,}969$$

Tools with four functions would yield 4^{14} or 268,435,456 patterns, and so on.

28:11 45 *Neurons aren't literally wired together:* This observation is courtesy of my colleague Dana Brooks in the Department of Electrical and Computer Engineering at Northeastern University.

29:05 *Physicists sometimes say that light travels in waves:* In this metaphor, I am not referring to wave-particle duality but to the myth of luminiferous ether described in an appendix entry in lesson no. 1. See 7half.info/wave.

Lesson 3. Little Brains Wire Themselves to Their World

00:08 47 *many newborn animals are more competent than newborn humans:* Of course, many newborn animals are less competent than newborn humans, such as the blind, bald little peanuts that are born to rats, guinea pigs, and other rodents.

05:12 51 *"Neurons that fire together, wire together":* This saying is attributed to the neuroscientist Donald Hebb, and the phenomenon is more formally known as Hebb's principle or Hebbian plasticity. Strictly speaking, the firing is not simultaneous—one neuron fires just before another. See Hebb's book *The Organization of Behavior: A Neuropsychological Theory*. See 7half.info/hebb.

10:57 54 *It has more of a lantern:* The wonderful metaphor of a "lantern of attention" is courtesy of psychologist Alison

Gopnik, who studies the cognitive development of children. See her book *The Philosophical Baby: What Children's Minds Tell Us About Truth, Love, and the Meaning of Life*.

Besides sharing attention, other abilities are probably important to developing a spotlight of attention. One is the brain's control of the head, an ability that develops over the first few months of life. Another is control of the muscles of the eye, called oculomotor control, which improves during the first few months of life.

I should also note that scientists still debate how much attentional capacity infants are born with and what kind of attentional capacities they might be. Many scientists who study development think that infants are genetically programmed to attend to certain features of the world (such as whether something is alive or not) and that subsequent development scaffolds onto these innate abilities. See 7half.info/lantern.

26:23 61 *it's far cheaper to eradicate poverty than to deal with its effects decades later:* Childhood poverty costs society close to one trillion dollars per year, according to a 2019 report by the National Academies of Sciences, Engineering, and Medicine, *A Roadmap to Reducing Child Poverty*. The cost of lifting children out of poverty, the report states, is far less than the price paid for the consequences of poverty after the children grow up. My colleague psychologist Isaiah Pickens points out the irony that in our culture, we start to treat people as more responsible for their actions right around the time that the ill effects of poverty and adversity manifest themselves in more serious ways. See 7half.info/poverty.

Lesson 4. Your Brain Predicts (Almost) Everything You Do

00:11 64 *a man who served in the Rhodesian army:* Another take on this story appears in my 2018 TEDx Talk "Cultivating Wisdom: The Power of Mood," which you can view at 7half.info/tedx.

04:09 66 *ambiguous scraps of sense data:* Sense data is not only ambiguous but also incomplete. Information about the world and the body is lost when it's processed by your retina, cochlea, and other sensory organs and sent to the brain. Scientists still debate just how much is lost, but everyone agrees that neurons convey less sense data from the world and the body than is available to be perceived. See 7half.info/incomplete.

05:32 *Your brain assembles these bits into memories:* The idea that your brain uses past experiences to give incoming sense data meaning is in some ways similar to immunologist and neuroscientist Gerald Edelman's proposal that your ongoing conscious experience is the "remembered present." See 7half.info/present.

07:47 69 *line drawings:* The three figures are a submarine going over a waterfall, a spider doing a handstand, and a ski jumper looking at spectators far below before pushing off.

The figures are Droodles excerpted from *The Ultimate Droodles Compendium—The Absurdly Complete Collection of All the Classic Zany Creations of Roger Price*, © 2019 Tallfellow Press, Inc. Used by permission.

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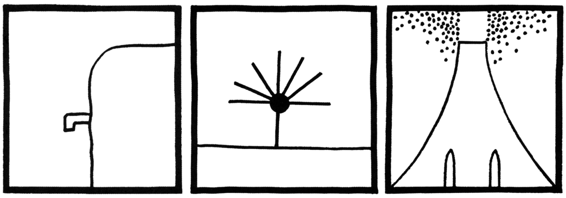

10:11 70 *"the beholder's share":* This idea about the perception of artwork originated with the art historian Alois Riegl, who called it "the beholder's involvement." The later term *beholder's share* was coined by art historian Ernst Gombrich. See 7half.info/art.

13:47 71 *an everyday kind of hallucination:* I referred to conscious perception and experience as an everyday hallucination for a number of years before discovering that philosopher Andy Clark eloquently makes the same point, calling conscious experience a "controlled hallucination." See his book *Surfing Uncertainty: Prediction, Action, and the Embodied Mind*. Today, other scientists also describe experience in this way, notably the neuroscientist Anil Seth in his engaging TED Talk "Your Brain Hallucinates Your Conscious Reality." See 7half.info/hallucination.

32:42 81 *who bears responsibility when you behave badly:* Some material on this topic comes from my 2018 TED Talk "You Aren't at the Mercy of Your Emotions — Your Brain Creates Them," which you can view at 7half.info/ted.

Lesson 5. Your Brain Secretly Works with Other Brains

11:31 89 *experiments that demonstrate the power of words:* My lab's research on the power of words, in which participants listened to scenarios and imagined them while having their brain scanned, is discussed in several papers. See 7half.info/words.

13:07 *many brain regions that process language* also control the insides of your body: The brain regions that scientists call the "language network" overlap to a large extent with a network called the "default mode network," particularly on the left side of the brain. The default mode network is part of a larger system that controls the internal systems of your body, including your autonomic nervous system (which controls your cardiovascular system, respiratory system, and other organ systems), immune system, and endocrine system (which controls hormones and metabolism). See 7half.info/language-network.

15:52 91 *This includes physical abuse, verbal aggression:* Verbal aggression, at least the milder kind, depends on context. Not all profanity is verbal aggression. For example, women sometimes call each other *bitch* as a term of endearment or even empowerment. Likewise, words that are positive in one context can be aggressive in another. If you say something romantic to your partner who then responds, "Come here and say that," your brain may predict that a kiss is in your future. If you stand up to a bully who then responds, "Come here and say that," your brain may predict a threat. See 7half.info/aggression.

17:14

91 *a long period of chronic stress can harm a human brain:* Studies show that chronic stress eats away at the brain and the body over the long term regardless of whether the stress stems from ongoing physical abuse, sexual abuse, or verbal aggression. Scientific results like these are surprising and unwelcome, so it's helpful to consider the evidence in a bit of detail. I'll share just a small portion here; more details are at 7half.info/chronic-stress.

First of all, chronic stress causes brain atrophy. It reduces brain tissue, notably in parts of the brain that are important for body budgeting (allostasis), learning, and cognitive flexibility.

What exactly causes atrophy in a stressed brain? And how are these brain changes related to an increased likelihood of physical illness and a shorter life span? Scientists are still studying the biological details. One tricky bit is that we can't view the microarchitecture of a living human brain in enough detail to know exactly what changes occur. This is why scientists study the impact of stress on nonhuman animals and then carefully generalize to humans where possible. For example, see the research of neuroendocrinologist Bruce McEwen.

Chronic verbal abuse in childhood has long-lasting effects. For example, in a study of 554 young adults, scientists asked the participants to rate their exposure to verbal abuse from parents and peers when they were children. The scientists found that people who reported exposure to verbal abuse in childhood were more likely to experience anxiety, depression, and anger during young adulthood. Incredibly, these associations were larger than those observed for people who reported physical abuse by a family member and comparable to those observed for people who reported sexual abuse by someone outside the family. These findings are consistent with the hypothesis that chronic verbal abuse in childhood predisposes people to mood disorders in young adulthood. However, an alternative interpretation is that people who suffer from mood disorders remember more abuse, including verbal abuse. That's why it's important to have other studies to help us determine which of these two hypotheses is more likely to be correct.

In one such study, scientists measured the biological impact of growing up in a harsh or chaotic family with a lot of verbal criticism and conflict. Researchers measured a marker of inflammation (interleukin 6) and a marker of metabolic dysfunction (cortisol resistance) in 135 female adolescents. Participants were interviewed four times during an eighteen-month period. Participants who reported a harsher family environment with more verbal aggression showed more immune dysfunction and more metabolic dysfunction as time went on, whereas participants with average exposure showed no change in these markers, and those with the lowest exposures were healthier. Other studies find similar results—swimming in a sea of sustained aggression places adolescents on a developmental trajectory that can lead to physical and mental illness.

An increasing number of studies consistently reveal a link between sustained social stress, usually involving verbal aggression, and an increased incidence of psychiatric and physical disease. For example, there is evidence that verbal aggression can alter the immune response sufficiently to reactivate latent herpes viruses, reduce the benefits of common vaccines, and slow the healing of wounds. These are not studies of vulnerable people but of average people who were drawn from across the political spectrum. I should also point out that these findings hold whether or not test subjects report *experiencing* intense stress. See 7half.info/chronic-stress.

18:58

92 *the effects of stress on eating:* I mentioned two studies on stress and how your body metabolizes food. Both studies are by psychologist Janice K. Kiecolt-Glaser and her colleagues. The figure of eleven pounds per year assumes that you're stressed before one meal each day—104 calories times 365 days divided by 3,500 calories per pound. I like to offer up these scientific tidbits when I am at a flagging dinner party that needs a bit of livening up. See 7half.info/eat.

Lesson 6. Brains Make More than One Kind of Mind

00:07

98 *When people from the island of Bali in Indonesia are afraid, they fall asleep:* I borrowed this example from the psychologists Batja Mesquita and Nico Frijda. They cite an ethnology, *Balinese Character*, published in 1942, in which anthropologists Gregory Bateson and Margaret Mead observed that people who lived in Bali would often fall asleep when faced with events that were unfamiliar or frightening. Their interpretation was that the people were avoiding something scary, like you might do by closing your eyes during a gruesome or suspenseful movie. According to Bateson and Mead, sleeping was a socially approved response to fear; the Balinese called it *takoet poeles*, which translates to "in a fright sleep." See 7half.info/sleep.

03:19 100 *Thunberg's mind is on the autism spectrum:* Greta Thunberg describes herself as having Asperger's syndrome, but the proper diagnostic term today is *autism spectrum disorder*. See 7half.info/thunberg.

03:55 *Hildegard of Bingen:* Hildegarde of Bingen believed that her visions, which she called "the Shade of the Living Light," were instructions from God. Over the years, she documented her visions in words and artwork. Just to be clear, I am *not* diagnosing Hildegard of Bingen with schizophrenia or any other mental illness. Rather, I am making a general point that one person's mystical experience can be another person's symptom of illness, depending on the historical or cultural context. A number of scholars have retrospectively diagnosed Hildegard of Bingen with various disorders, but this sort of activity should be done with extreme caution. See 7half.info/bingen.

05:53 101 *the sort of mind that might emerge from Pocketknife Brain:* When applied to the mind (instead of the brain), the clash of Pocketknife versus Meatloaf is perhaps best known as nativism versus empiricism. This philosophical debate is about whether knowledge is inborn or learned from experience, and it has raged for thousands of years. Psychologists sometimes call this debate faculty psychology versus associationism. See 7half.info/nativism.

variation is a prerequisite for natural selection to work: In his book *On the Origin of Species,* Charles Darwin proposed that variation among individuals in a species is a prerequisite for natural selection during the course of evolution. A species is a diverse group of individuals, and those who are most suited to a particular environment are more likely to survive and pass their genes to their offspring (who also will be more likely to survive and breed). Darwin's idea about variation, known as *population thinking*, is one of his greatest innovations, according to the evolutionary biologist Ernst Mayr. For a primer, see Mayr's book *What Makes Biology Unique*, and for a more thorough treatment, see his book *Toward a New Philosophy of Biology*. See 7half.info/variation.

08:56 102 *Myers-Briggs Type Indicator:* The MBTI and various other personality tests have no more scientific validity than horoscopes. Years of evidence show that the MBTI does not live up to its claims and does not consistently predict job performance. Nonetheless, these kinds of personality tests lure otherwise capable managers into making decisions that benefit neither their employees nor their company. Why do the test results seem so true when you receive them? Because the test asks what you *believe* about yourself. The results summarize those beliefs and give them back to you, and wow, they fit so well! The bottom line is this: You can't measure behavior by asking people their opinions about their behavior. You have to *observe* that behavior in multiple contexts. (Furthermore, the same people may be honest in some contexts and dishonest in others, introverted in some contexts and extroverted in others, and so on.) See 7half.info/mbti.

13:57 105 *Feelings of affect range from pleasant to unpleasant, from idle to activated:* Affect is described by a mathematical structure depicted in the figure on page 105, called a *circumplex,* which was first discussed by the psychologist James A. Russell. A circumplex represents relations using the geometry of a circle; in this case, the relations among affective feelings. The term *circumplex* means "circular order of complexity" to indicate that the feelings in question are characterized simultaneously by at least two basic psychological features. The circle maps how similar the feelings are to one another, and the two dimensions describe the properties of similarity. See 7half .info/circumplex.

16:14 106 *an app or a smart watch to regulate your body budget:* This analogy also appears in my 2018 TEDx Talk "Cultivating Wisdom: The Power of Mood," which you can view at 7half.info/tedx2.

Lesson 7. Our Brains Can Create Reality

03:12 111 *The boundary between social reality and physical reality is porous:* This porous boundary is easily revealed by experiments about the sense of taste, such as the studies I mention in this lesson about wine and coffee. A more serious example can be found in lesson no. 3, where we discussed the vicious cycle of poverty. Societal attitudes toward people in poverty, which are social reality, affect the physical reality of brain development, which then increases the likelihood that those little brains will grow to become adults who live in poverty. See 7half.info/porous.

04:15 112 *a suite of abilities that I'll call the Five Cs:* The *Five Cs* is my own term for a collection of characteristics that evolve together to reinforce one another and that give humans the capacity to create social reality on a large scale. Four of these Cs—creativity, communication, copying, and cooperation—are inspired by research from evolutionary biologist Kevin Laland, and my account draws heavily from his book *Darwin's Unfinished Symphony: How Culture Made the Human Mind*. Laland does not discuss the role of social reality in human evolution, but he discusses the related concept of cultural evolution. See 7half.info/5C.

07:12

113 *explorers in the 1800s:* The example of explorers who cooperated with indigenous people to survive comes from the anthropologist Joseph Henrich's book *The Secret of Our Success: How Culture Is Driving Human Evolution, Domesticating Our Species, and Making Us Smarter.* See 7half.info/explore.

09:14

114 *You also need the fifth C,* compression: Compression occurs in many parts of the brain. Here, we're discussing the compression that occurs in the cerebral cortex, particularly in layers 2 and 3. The human brain has souped-up wiring in these critical layers, which enhances compression.

A big, complex brain with the capacity to compress, however, is probably not sufficient on its own for small bits of social reality to cohere into a civilization. You also need the right metabolic conditions, including agriculture, to supply enough energy to build and maintain a human brain with its souped-up wiring. For a useful discussion, see Kevin Laland's book *Darwin's Unfinished Symphony*. Also see evolutionary biologist Richard Wrangham's book *Catching Fire: How Cooking Made Us Human*. See 7half.info/metabolic.

11:10

115 *sense data from your eyes, ears, and other sense organs:* Sense data is collected by various sense organs in your body, such as your eyes, ears, nose, and so on, and converted into neural signals that the brain can use. Sense data usually passes through several way stations before reaching the brain. For example, in vision, the cells in your retina (the thin layer that lines the back of your eyeball) are called photoreceptors and they convert light energy to neural signals. These neural signals travel along a bundle of nerve fibers called the optic nerve. A majority of your optic nerve fibers arrive at a cluster of neurons called the lateral geniculate nucleus, which is part of a brain structure called the thalamus; this structure's main job is to relay the sense data from your body and the surrounding world to your cerebral cortex. From there, the neural signals make their way to neurons at the very back of your cortex, in the occipital lobe, also known as your primary visual cortex. A small number of axons branch away from your optic nerve and travel to other parts of the subcortex, including your hypothalamus, which is a subcortical brain structure that is important for regulating the internal systems of your body.

Most of your sensory systems work in a similar way, except for the system that gives you your sense of smell, known as the olfactory system. The cells that convert chemicals in the air into neural signals are located in a structure called the olfactory bulb. These cells send information directly to the cerebral cortex, bypassing the thalamus. The neural signals bring olfactory sense data to your primary olfactory cortex, which is part of a brain region called the insula, which itself is a portion of the cerebral cortex between the temporal and frontal lobes. See 7half.info/sense-data.

12:13 116 *compression makes it possible for your brain to think* abstractly: Scientists are still working out the details of how the brain compresses information and how compression leads to abstraction. There is a long and vigorous debate about how much sensory and motor information remains in highly compressed abstractions. Some scientists propose that abstractions are *multimodal*, meaning they include information from all senses; others propose that abstractions are *amodal*, meaning they include no sense data. My view is that the evidence favors the multimodal hypothesis. For example, the most compressed summaries are created in areas of the cerebral cortex that neurologists and neuroanatomists call *heteromodal*, meaning that those areas manage information from multiple senses as well as motor information.

Presumably, a brain can achieve abstraction by other means than compression, because other animals without huge brains (such as dogs) or without a cerebral cortex (such as bees) can treat two things as similar based on their function—that is, they can do abstraction to some extent. See 7half.info/abstract.

17:45 119 *the Five Cs intertwine and reinforce one another:* This idea and its relevance to human evolution is the subject of an ongoing scientific debate. One evolutionary perspective, known as the "modern synthesis," combines the science of genes (beginning with Mendelian genetics) and Darwin's theory of natural selection and assumes that genes are the only stable way to transmit information from one generation to the next. An example would be the selfish-gene hypothesis by the evolutionary biologist Richard Dawkins. The other perspective, known as the "extended evolutionary synthesis," involves the various Cs and draws on findings that identify other sources of information transfer that are stable across generations (e.g., sense data from the visual environment that wires a brain during development, and the cultural transmission of information). The extended evolutionary synthesis, which considers evolutionary and developmental ("evo-devo") neuroscience, proposes other means of transfer, such as epigenetics and niche construction, as well as cultural evolution and gene-culture co-evolution. Examples are the views of Barbara Finlay and Kevin Laland. The breadth of this scientific debate is beyond the scope of our lessons here, but you can find a reading list at 7half.info/synthesis.

20:01 120 *it imposes a sovereign function on the stick that goes beyond the physical:* Chimpanzees and many other nonhuman animals have dominance hierarchies, but those hierarchies are neither established nor maintained by social reality. If every chimp in a troop agrees on which member is the alpha male, it is because the alpha will kill other animals who challenge him. Killing is physical reality. Most human leaders today stay in power without murdering their opponents. See 7half.info/sticks.

"We don't create a fantasy world to escape reality. We create it to be able to stay": This quote about fantasy worlds by author and cartoonist Lynda Barry comes from her book *What It Is*. See 7half.info/barry.

23:45

121 *physical characteristics such as skin tone:* Skin pigmentation has evolved and re-evolved in relation to the amount of ultraviolet light in the environment. Lighter skin tones are better adapted for environments with less ultraviolet (UV) light. Lighter pigmentation allows the skin to absorb more light and produce more more vitamin D, which is important for bone growth, bone strength, and a healthy immune system. In contrast, darker skin tones are better adapted for environments with more UV light, because darker pigmentation prevents the skin from absorbing too much light. This in turn slows the destruction of vitamin B_9, folic acid, which is important for cell growth and metabolism and is particularly important in early pregnancy (since sunlight breaks down folate). The intensity of UV rays is dictated by how close you are to the equator, but the amount of UV light that actually penetrates your skin depends on your skin pigmentation. A more detailed discussion can be found in anthropologist Nina Jablonski's book *Living Color: The Biological and Social Meaning of Skin Color*. See 7half.info/skin.

See more details at sevenandahalflessons.com!