RESEARCH REPORT · NOVEMBER 2026

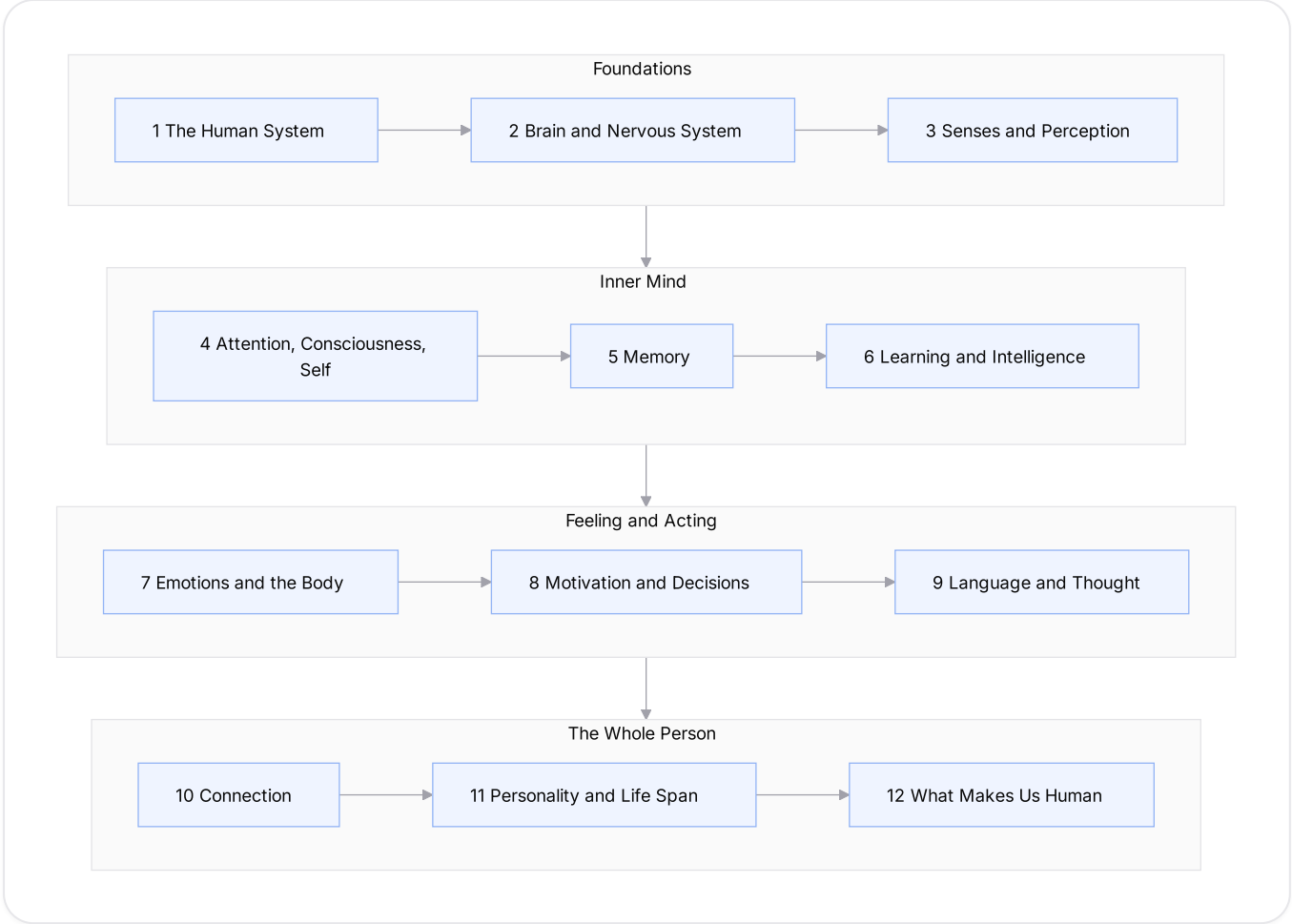
What Makes Us Human

The science of body, brain and mind. How we sense, feel, remember, think, decide, learn and connect, written in plain words. Human science only. The companion report covers how people try to copy a human with AI.

12	40	86 B	~20%
chapters	diagrams	neurons in one brain	of body energy used by the brain

HOW TO READ THIS

The report moves from the body up to the social world. Every chapter ends with key takeaways, a table of signals you can measure on a living person, and sources.



Contents

1. The Human System
2. The Brain and Nervous System
3. Senses and Perception
4. Attention, Consciousness and the Self
5. Memory
6. Learning and Intelligence
7. Emotions and the Body
8. Motivation and Decision Making
9. Language, Thought and Imagination
10. Connection: The Social Human
11. Personality, Identity and the Life Span
12. What Makes Us Human, and What Is Still Unknown

CHAPTER 01

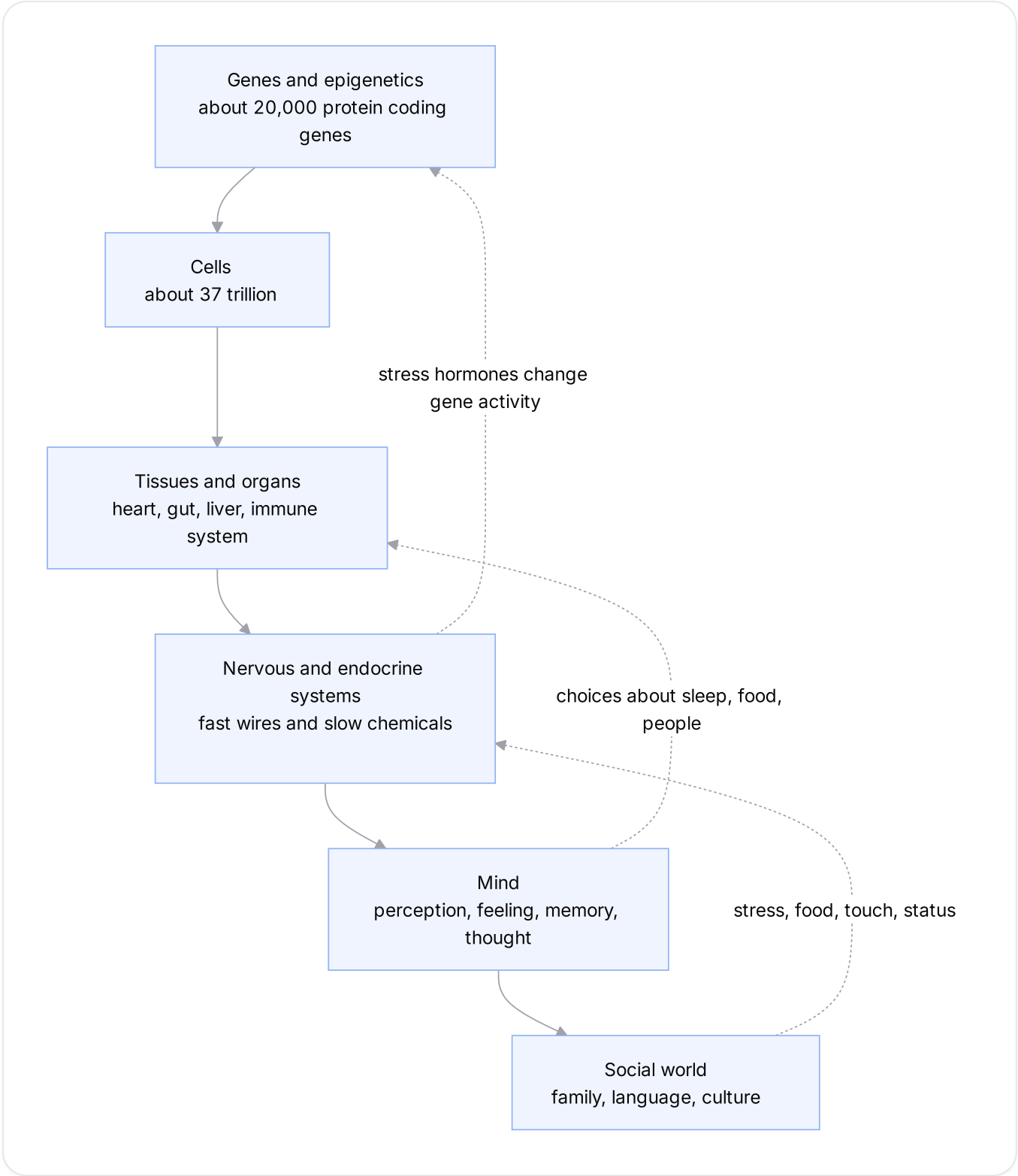
The Human System

A human being is not a brain riding around in a body. It is a stack of living layers that talk to each other all the time. Genes build cells. Cells build organs. Organs keep a body alive. A nervous system ties the organs together and runs a mind. And that mind lives inside a family, a culture and a history. This chapter gives a map of those layers. It explains how the body and brain form one loop, how the body keeps itself stable and plans ahead, how the human brain grew so large, and what scientists mean when they say "mind". The rest of the report zooms in on each part of this map.

A person as a stack of layers

Think about a simple moment. You skip lunch and snap at a friend in the afternoon. Where did that snap come from? Your blood sugar dropped. Hormones changed. Your brain read those signals as "something is wrong". It made you quicker to see a threat. Then a social habit, the way you learned to deal with friction, decided what you actually said. One small event touched almost every layer of the human system at once.

Scientists split a person into levels so they can study one level at a time. Each level has its own units and its own rules. But no level works alone.



The arrows go both ways. This is the key idea of the whole chapter. Genes shape the brain. But a lonely or stressful life also changes which genes are switched on. Scientists call this epigenetics. It means chemical tags on DNA that turn genes up or down without changing the code itself. The social world reaches all the way down to the cell.

A few numbers help set the scale. An adult body has about 37 trillion human cells. It also carries a similar number of gut bacteria, about 38 trillion by one careful estimate. You have

about 20,000 genes that code for proteins. The brain holds about 86 billion neurons. Each of these numbers is an estimate with real error bars. But they show that a person is a very large and very busy system.

The body and brain loop

Most people picture the brain as a boss that sends orders down to the body. That picture is only half right. Far more signals travel up from the body to the brain than the other way. The vagus nerve is the main cable between the brain and the organs of the chest and belly. About 80 percent of its fibers carry news upward, from the gut, heart and lungs to the brain.

So the brain is always listening to the body. Your heart rate, breathing, gut, blood sugar and immune system all report in. The sense of these inner signals is called interoception. Chapter 3 covers it as a sense. Chapter 7 shows how it shapes emotion.

The loop runs in both directions:

1. The body sends a stream of signals to the brain. These come through nerves and through chemicals in the blood.
2. The brain builds a picture of what the body needs right now.
3. The brain sends commands back. Some go through nerves, like a faster heartbeat. Some go through hormones, like a rise in cortisol.
4. The body changes. The new state is reported back. The loop starts again.

This loop never stops, even in sleep. It is why a bad night of sleep can make the whole world feel hostile. It is why a racing heart can feel like fear even when nothing is wrong. Mind and body are not two things that sometimes meet. They are one system with a fast inner conversation.

Homeostasis and allostasis

In the 1800s the French doctor Claude Bernard noticed that the inside of the body stays steady while the outside world changes. He called this the "inner environment". In the 1920s the American physiologist Walter Cannon gave it a name that stuck: homeostasis. It means keeping key values near a set point. Body temperature stays near 37 °C. Blood sugar, salt, acidity and oxygen all stay in narrow ranges.

Homeostasis works like a thermostat. Something drifts away from its target. A sensor notices. A response pushes it back. You get too hot and you sweat. Your blood sugar rises and insulin brings it down.

But a thermostat only reacts after a problem shows up. In 1988 Peter Sterling and Joseph Eyer argued that the body does something smarter. They called it allostasis, which means "stability through change". The brain does not wait for errors. It predicts what the body will need and adjusts in advance. Your blood pressure starts to rise before you stand up. Your body releases insulin at the first taste of food, before sugar reaches the blood. Your cortisol climbs in the early morning to get you ready for the day.

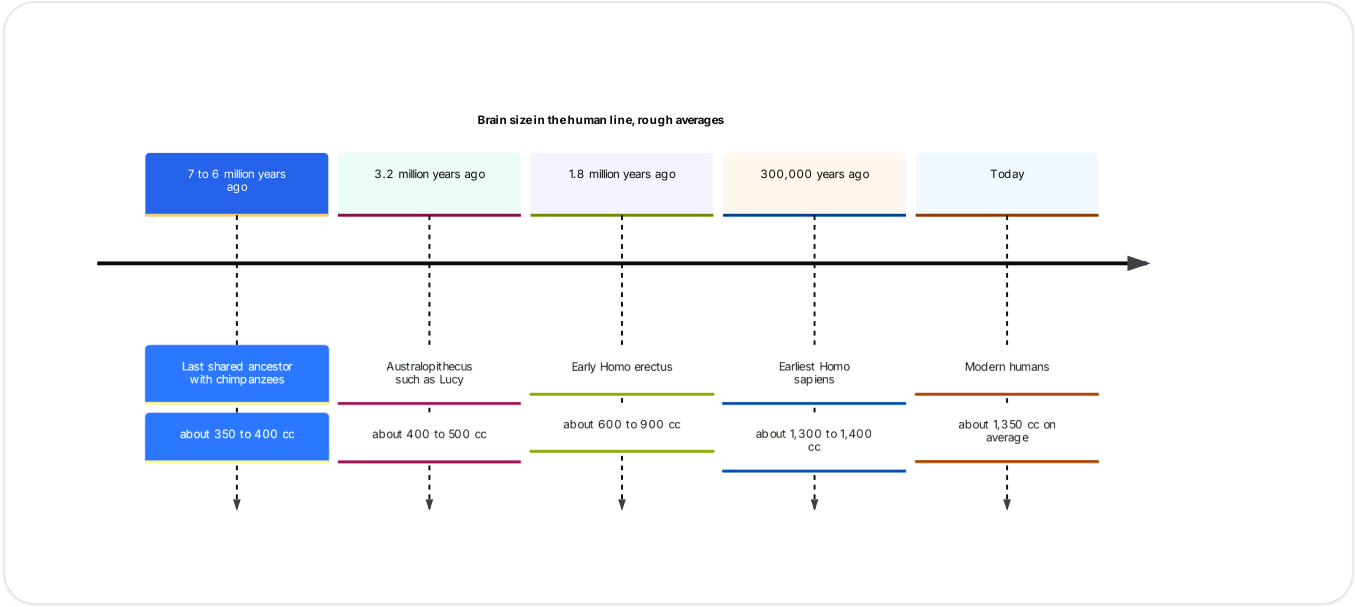
FEATURE	HOMEOSTASIS	ALLOSTASIS
Main idea	Keep values at a fixed set point	Change set points to meet expected demands
Timing	Reacts after an error	Acts before the need arrives
Who is in charge	Mostly local feedback loops	The brain coordinates the whole body
Daily example	Sweating when you are already hot	Heart speeds up as you walk on stage
Cost when overused	Rare	"Allostatic load": wear and tear from long stress

The cost of allostasis matters a lot for understanding people. The neuroscientist Bruce McEwen showed that the body pays a price when it stays in "get ready" mode for months. He called this price allostatic load. Long stress keeps cortisol and blood pressure high. Over years this can harm the heart, the immune system, sleep and even parts of the brain linked to memory. So the same system that keeps us alive in a crisis can wear us down when the crisis never ends.

Many scientists now see allostasis as the brain's main job. In this view the brain exists first to run the body's budget of energy, water and salt. Thinking, feeling and planning all grew on top of that job. This is a strong claim and still debated. But it is a useful lens. A lot of human behavior makes more sense when you ask "what body budget problem is this solving?"

How the human brain got so big

Our brain is large for our body. It is about three times the size you would expect for a primate of our weight. It did not get this way overnight.



The numbers above are rough. Skull sizes vary a lot, and fossils are rare. Neanderthal brains were as large as ours or slightly larger. Our brains also seem to have shrunk a little in the last 10,000 to 20,000 years. Why that happened is debated.

Size is not the whole story. The neuroscientist Suzana Herculano-Houzel counted neurons by dissolving brains into a soup and counting cell nuclei. She found that the human brain is in many ways a scaled up primate brain. It has about 86 billion neurons. About 16 billion sit in the cerebral cortex, the wrinkled outer sheet. About 69 billion sit in the cerebellum at the back. What is special is that primate brains pack neurons densely, and ours is the largest primate brain. So we simply have the most cortical neurons of any primate.

The cortex also grew unevenly. The areas for planning, language and linking ideas grew more than the areas for basic seeing and moving. These "association areas" are the parts that mature last in childhood.

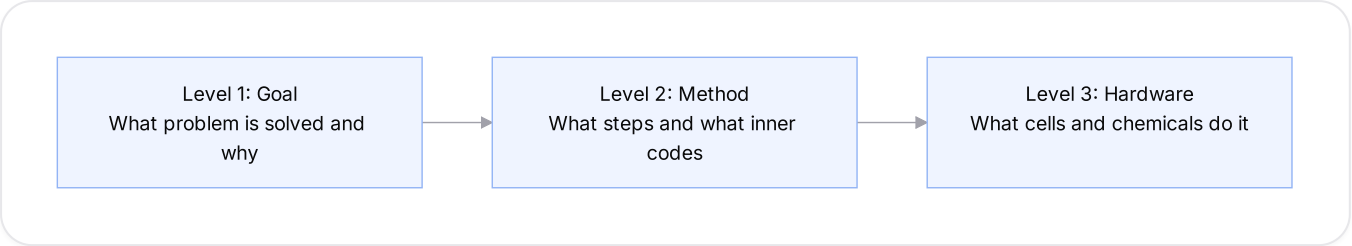
Three other changes matter as much as size:

- **Cooking and diet.** A big brain needs a lot of fuel. Many scientists think cooked food and meat made the extra energy possible. This idea is supported but still argued over.
- **A long childhood.** A human baby is born with a brain about a quarter to a third of adult size. A chimp is born with a brain far closer to its adult size. Our brains keep growing for years outside the womb, so the world shapes them. At around age five, a child's brain burns close to half of the body's resting energy. Kids grow slowly in body during those years, perhaps to pay for the brain.
- **A social niche.** Human children need years of care from many adults. Living in large groups with long lasting bonds may have pushed the brain to track other minds. This "social brain" idea is popular and has evidence behind it. But it is one of several theories.

The long childhood is important for the reader's later goal. A human mind is not built from genes alone. It is built over two decades by a body that is constantly learning from people around it.

Marr's three levels

How should we even try to explain a mind? In the 1970s the British neuroscientist David Marr gave a simple tool. He said you can describe any system that handles information at three levels. You need all three to really understand it.



Take a familiar act: catching a ball.

- **Goal level.** The problem is to get the hand to the spot where the ball will be. You must predict a path from a few glances.
- **Method level.** One known trick is to run so that the ball seems to rise at a steady rate in your view. If you do that, you end up in the right place without doing any math.
- **Hardware level.** The eyes, the motion areas of the visual cortex, the cerebellum and the spinal cord carry out that trick.

Marr's levels help in two ways. First, they stop us from mixing up questions. "Why do people fear snakes?" is a goal question. "Which brain area fires?" is a hardware question. Both are fair, but they are different. Second, they remind us that the same goal can be met by different methods, and the same method by different hardware. Two people can reach the same decision in different ways. A brain scan alone will not tell you which way they used.

Later chapters move between these levels on purpose. Chapter 2 is mostly about the hardware. Chapters 5 to 8 are mostly about methods and goals.

What scientists mean by "mind"

The word "mind" means different things to different experts. That causes a lot of confusion. In everyday science it usually means the set of processes that let a person take in the world,

feel, remember, think, decide and act. Under this working definition the mind is what the brain and body do, the way digestion is what the gut does.

There are a few other angles worth knowing:

- **The mind as information processing.** Cognitive scientists treat the mind as a set of steps that turn sensations into actions. This fits well with Marr's levels.
- **The embodied mind.** Many researchers stress that the mind is not only in the head. It depends on the body, its gut signals, its posture and its tools. Your sense of distance changes when you are tired or carrying a heavy pack, at least in some studies. Some of those findings are disputed.
- **The social mind.** Much of what we think comes from language and culture. We think in words we learned from others. We remember events by telling them as stories to other people.
- **The conscious mind.** This is the hardest part. Why do these processes feel like anything at all from the inside? Philosophers call this the "hard problem". There is no agreed answer. Chapter 4 treats it in depth.

Most scientists today accept that the mind depends fully on the brain and body. Damage the brain and you change the mind. But how physical events give rise to felt experience is still an open question. It is honest to say so at the start.

How the rest of the report fits

This chapter is the map. Chapter 2 opens up the nervous system and its chemicals. Chapter 3 looks at the senses that feed it. Chapters 4 to 9 cover the inner mind: attention, memory, learning, emotion, decisions and language. Chapters 10 and 11 cover connection, personality and change over a life. Chapter 12 asks what is truly unique to humans and what is still unknown.

Measurable signals

LAYER	WHAT COULD BE MEASURED ON A LIVING PERSON	TYPICAL TOOL
Genes	DNA sequence, some epigenetic marks	Saliva or blood test
Body budget	Heart rate, heart rate variability, blood pressure	Chest strap, wrist sensor, cuff
Hormones	Cortisol across the day	Saliva, hair or blood samples
Metabolism	Blood sugar over 24 hours	Continuous glucose monitor
Sleep and rhythm	Sleep timing and stages	Wrist sensor, sleep lab EEG
Long term stress	Allostatic load index	Blend of blood pressure, waist size, lipids, cortisol
Social world	Size and contact of a person's network	Diaries, surveys, phone logs

Key takeaways

- A person is a stack of layers, from genes to culture. Signals flow both up and down this stack.
- The brain and body form one loop. Far more signals go up from the body than down to it.
- Homeostasis keeps values steady by reacting. Allostasis keeps us alive by predicting. Long use of allostasis wears the body down.
- The human brain is a large primate brain with about 86 billion neurons. A long childhood lets the world shape it.
- Marr's three levels (goal, method, hardware) keep questions about the mind clear.
- "Mind" in science means what the brain and body do. How that feels like something from the inside is still unsolved.

SOURCES AND FURTHER READING

- McEwen, B. S. (1998). Protective and damaging effects of stress mediators. *New England Journal of Medicine*, 338, 171 to 179. https://doi.org/10.1056/NEJM199801153380307
- Sterling, P. (2012). Allostasis: A model of predictive regulation. *Physiology and Behavior*, 106(1), 5 to 15. https://doi.org/10.1016/j.physbeh.2011.06.004
- Herculano-Houzel, S. (2012). The remarkable, yet not extraordinary, human brain as a scaled-up primate brain and its associated cost. *PNAS*, 109, 10661 to 10668. https://doi.org/10.1073/pnas.1201895109
- Kuzawa, C. W., et al. (2014). Metabolic costs and evolutionary implications of human brain development. *PNAS*, 111(36), 13010 to 13015. https://doi.org/10.1073/pnas.1323099111
- Barrett, L. F., and Simmons, W. K. (2015). Interoceptive predictions in the brain. *Nature Reviews Neuroscience*, 16, 419 to 429. https://doi.org/10.1038/nrn3950
- David Marr and his three levels of analysis. Wikipedia. https://en.wikipedia.org/wiki/David_Marr_(neuroscientist)
- Stanford Encyclopedia of Philosophy. Consciousness. https://plato.stanford.edu/entries/consciousness/

CHAPTER 02

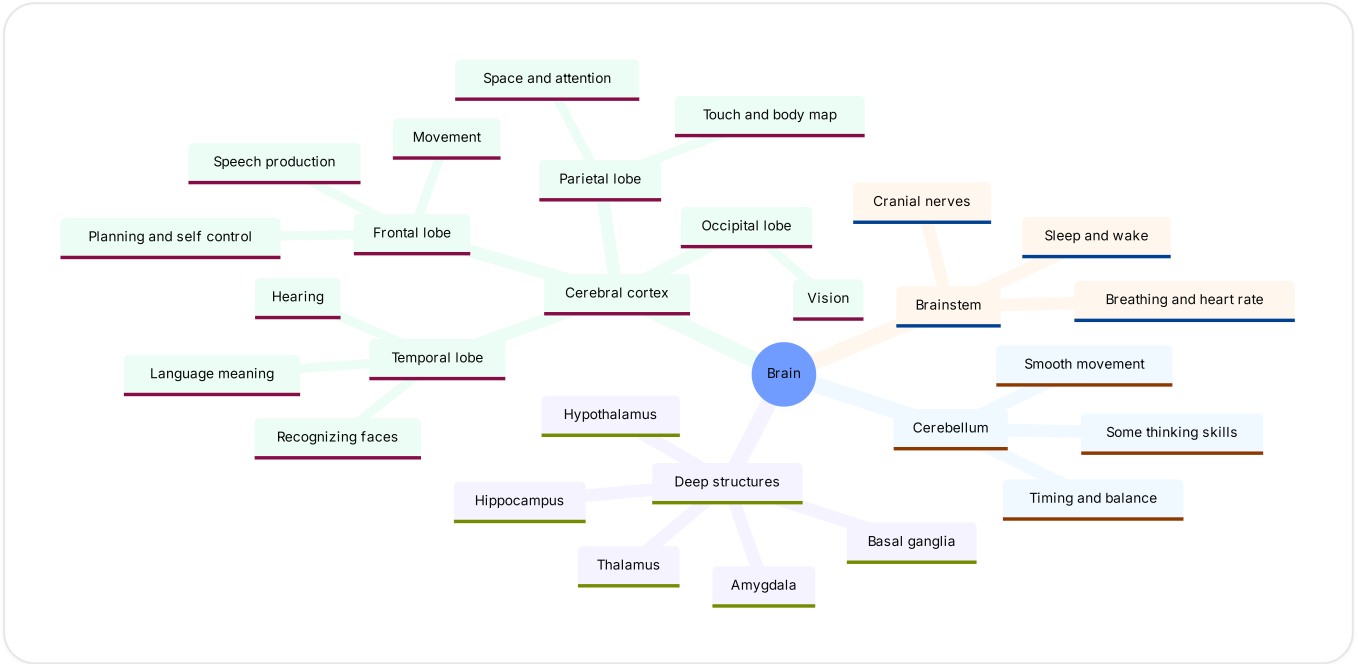
The Brain and Nervous System

The brain weighs about 1.4 kg, roughly 2 percent of body weight, yet it uses about 20 percent of the body's resting energy. It works through two kinds of messages. Fast electrical and chemical signals pass between nerve cells in thousandths of a second. Slower hormones travel in the blood and change the whole body over minutes to weeks. This chapter walks through the main parts of the brain, how nerve cells talk, the chemicals that tune mood and attention, the hormone systems that run stress and growth, the large networks that switch on and off as we think, how the brain rewires itself, and the tools scientists use to watch it at work.

The map: lobes, deep structures, brainstem and cerebellum

The brain has three big parts you can see from the outside. The cerebrum is the large wrinkled top. The cerebellum is the small ridged ball tucked at the back. The brainstem is the stalk that joins the brain to the spinal cord.

The outer layer of the cerebrum is the cortex. It is a sheet only 2 to 4 mm thick. It is folded so that a large area fits inside the skull. If you could flatten it, one side would be roughly the size of a large napkin. Each side of the cortex is split into four lobes.



Below the cortex sit several deep structures. Each does many jobs, so the short labels below are simplifications.

STRUCTURE	MAIN JOBS IN PLAIN WORDS	WHAT HAPPENS WHEN IT IS DAMAGED
Thalamus	A relay hub. Most senses pass through it on the way to the cortex	Loss of feeling, problems with alertness
Hypothalamus	Runs hunger, thirst, body heat, sex drive and the hormone system	Eating, sleep and hormone disorders
Hippocampus	Forms new memories of events and maps of places	Cannot form new lasting memories
Amygdala	Flags things that matter, especially threats	Weak fear learning, trouble reading fear in faces
Basal ganglia	Pick which action to start, form habits	Parkinson's disease, Huntington's disease
Brainstem	Keeps you breathing and awake	Coma or death
Cerebellum	Fine tunes timing and movement	Clumsy, shaky movement, slurred speech

The cerebellum is a surprise for many people. It is small but holds about 69 of the brain's 86 billion neurons. Most of them are tiny granule cells. It helps us move smoothly, and newer work shows it also helps with timing in thought and language.

Two famous patients taught science a lot about this map. Phineas Gage survived an iron rod through his frontal lobe in 1848. Reports say his personality changed and he became less able to plan. Some of those reports were later exaggerated. The patient known as H.M. had both hippocampi removed in 1953 to stop seizures. Afterward he could not form new memories of events, but he could still learn new motor skills. That showed memory is not one thing. Chapter 5 returns to this.

Neurons, synapses and glia

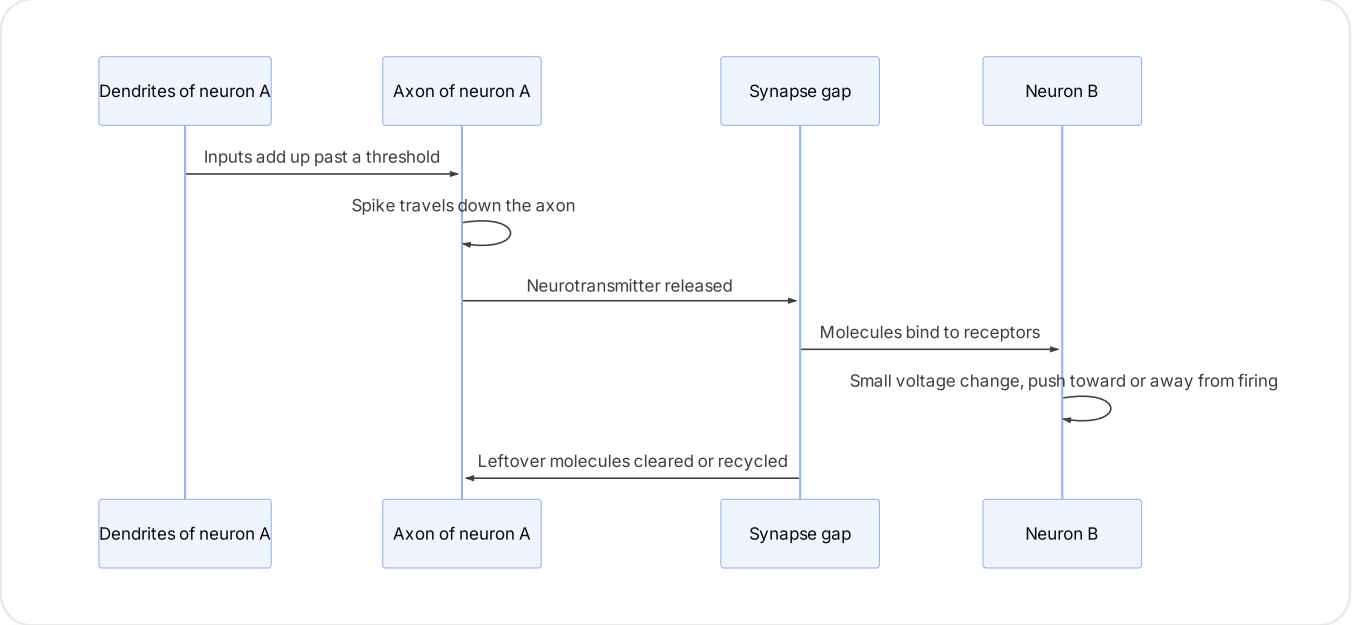
A neuron is a cell built to send signals. It has three main parts. Dendrites are branches that collect input. The cell body adds up that input. The axon is a long cable that carries the

output, sometimes as far as a meter, from your spine to your toe.

The signal along the axon is a short electrical pulse called an action potential, or a "spike". It lasts about a millisecond. It is all or nothing, like a click. A neuron says "more" by clicking faster, not louder. Many neurons fire a few times per second on average. Some can fire hundreds of times per second in short bursts.

Many axons are wrapped in a fatty coat called myelin. It works like insulation on a wire. It lets the spike jump along the axon. Signals in thin bare fibers move at about 1 meter per second. In thick myelinated fibers they move at up to about 100 meters per second.

At the end of the axon is the synapse. This is a tiny gap between two neurons. When a spike arrives, the axon releases chemical messengers called neurotransmitters into the gap. These drift across and lock onto receptors on the next cell. Some make the next cell more likely to fire. Some make it less likely. A single neuron can have thousands of synapses. The whole brain has something like 100 trillion. That is an estimate, and some counts go higher.



Neurons are not alone. Glia are the support cells of the nervous system. For years people said there were ten glia for every neuron. Careful counts now suggest the ratio is closer to one to one across the whole brain. Glia do real work:

- **Astrocytes** feed neurons, control blood flow and help clean up neurotransmitters.
- **Oligodendrocytes** make myelin in the brain and spinal cord.
- **Microglia** are the brain's immune cells. They also prune unused synapses during development.

Chemical messengers

Most fast signaling in the brain uses just two chemicals. Glutamate excites, meaning it pushes the next cell toward firing. GABA inhibits, meaning it holds the next cell back. A healthy brain keeps these two in balance. Too much excitation can cause seizures. Drugs that boost GABA, like alcohol and many sleeping pills, make people calm and sleepy.

Other chemicals work more like volume knobs. Small groups of cells deep in the brain send long branches everywhere. They release chemicals that change how whole regions respond. These are often called neuromodulators.

MESSENGER	WHERE IT COMES FROM	WHAT IT TUNES	COMMON MYTH TO AVOID
Glutamate	Most excitatory neurons	Fast signaling, learning at synapses	None common
GABA	Inhibitory neurons	Calming, timing, keeping balance	None common
Dopamine	Midbrain areas	Learning what is worth seeking, starting movement	It is not simply the "pleasure chemical". It tracks surprise about rewards and drives wanting more than liking
Serotonin	Raphe nuclei in brainstem	Mood, patience, impulse control, sleep	Most of the body's serotonin, about 90 percent, is in the gut, not the brain. The "low serotonin causes depression" story is too simple
Noradrenaline	Locus coeruleus in brainstem	Alertness, arousal, focus under pressure	None common
Acetylcholine	Basal forebrain, also nerve to muscle	Attention, memory, muscle contraction	None common
Endorphins	Pituitary and brain	Pain relief, calm after effort	The "runner's high" may owe as much to endocannabinoids
Oxytocin	Hypothalamus	Birth, nursing, bonding, trust	The "love hormone" label is overstated. It can also boost in group bias. Many nasal spray studies have failed to replicate

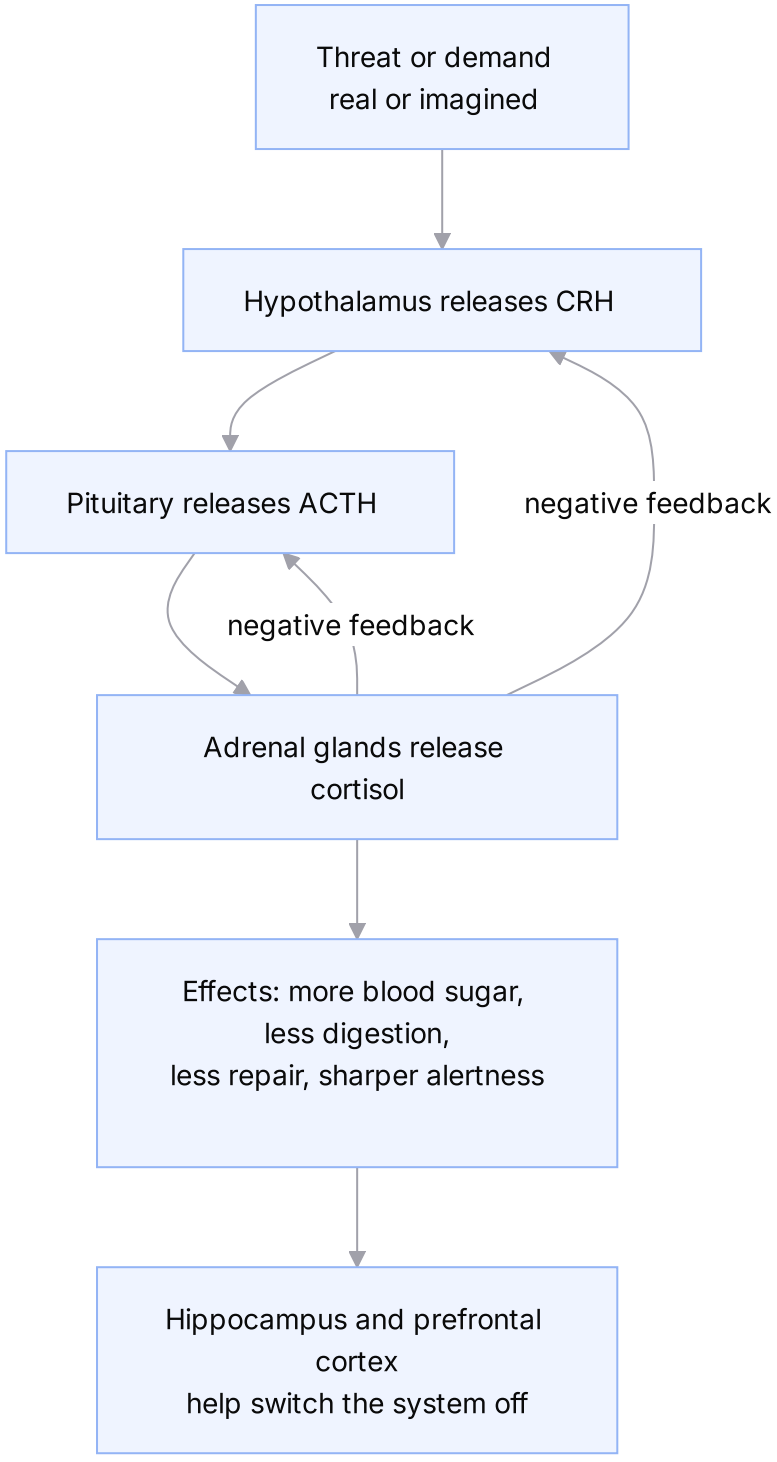
Two of these deserve a note on accuracy. Dopamine neurons fire more when a reward is better than expected and less when it is worse than expected. This "prediction error" finding by Wolfram Schultz in monkeys is one of the best supported ideas in brain science. Oxytocin

is less settled. Its role in birth and nursing is clear. Its role in human trust and bonding is real but smaller and messier than the headlines say.

Hormones and the endocrine system

Hormones are chemicals that glands release into the blood. They reach almost every cell. They act more slowly than neurotransmitters, but their effects last longer. The hypothalamus is the link between the two systems. It is a nerve center that also controls the master gland below it, the pituitary.

The best known hormone loop is the stress system, called the HPA axis. HPA stands for hypothalamus, pituitary and adrenal glands.



Cortisol is not a "bad" hormone. It rises every morning in a burst that peaks about 30 to 45 minutes after waking. It helps you get up and go. The problem is when it stays high for weeks. Then sleep, mood, memory and immunity can suffer. This links back to the idea of allostatic load from Chapter 1.

Other hormone systems shape the mind as well:

- **Adrenaline**, from the adrenal glands, gives the fast jolt of a fright within seconds.
- **Thyroid hormones** set the body's pace of energy use. Too little brings tiredness, low mood and slow thinking. Too much brings anxiety and a racing heart.
- **Sex hormones**, mainly testosterone, estrogen and progesterone, shape the body at puberty. They also affect mood, energy and sex drive across adult life. Their monthly and life span cycles change how some people feel. The size of their effect on complex behavior is often overstated in popular writing.
- **Melatonin**, from the pineal gland, signals "night" to the body.
- **Insulin, leptin and ghrelin** report on food and fat stores. They help set hunger.

The autonomic nervous system

Much of the nervous system works without our control. The autonomic nervous system runs the heart, gut, glands, pupils and blood vessels. It has two main branches that act like a gas pedal and a brake.

BRANCH	NICKNAME	WHAT IT DOES	YOU FEEL IT WHEN
Sympathetic	"Fight or flight"	Raises heart rate, widens pupils, sends blood to muscles, slows digestion, causes sweating	Your heart pounds before a speech
Parasympathetic	"Rest and digest"	Slows the heart, aids digestion, supports repair	You feel heavy and calm after a big meal
Enteric	"The gut's own brain"	Hundreds of millions of neurons, perhaps 200 to 600 million, that can run the gut on their own	Butterflies in the stomach

The vagus nerve carries most of the brake signals. Heart rate variability is the small change in time between one heartbeat and the next. It is a common way to estimate how strong this brake is. Higher variability at rest is linked to better health and better control of emotions in many studies. The link is real but modest, and the measure is easily affected by breathing, posture and fitness.

Large scale brain networks

Brain regions do not work alone. They form networks that rise and fall together. In the early 2000s researchers noticed that some regions became more active when people were resting than when they did a task. This led to the idea of the default mode network.

Three networks get the most attention:

- **The default mode network** is active when the mind turns inward. It is busy when you daydream, remember your past, imagine your future or think about other people. It includes the middle of the frontal lobe and the back middle of the parietal lobe.
- **The central executive network** is active when you hold information in mind and work on a problem. It includes the side parts of the frontal and parietal lobes. Doing mental math or following directions uses it.
- **The salience network** picks out what matters right now. It includes the anterior insula and anterior cingulate cortex. It helps switch the brain between the inward default mode and the outward executive mode. A sudden loud noise or a pang of hunger gets flagged here.

The psychiatrist Vinod Menon proposed a "triple network" model. It says many mental disorders involve trouble in how these three networks interact. For example, getting stuck in the default mode may fit with rumination in depression. This model is influential and useful, but it is a framework. It is not a settled account of any disorder.

Plasticity: the brain that changes

The brain is not fixed. Plasticity means its ability to change its wiring with experience. It happens at several scales:

- **Synapses** get stronger or weaker with use. A classic rule says "cells that fire together wire together". This is the basis of most learning.
- **Myelin** thickens on paths we use a lot, which speeds them up.
- **Maps** in the cortex can shift. In people who lose a hand, the area that once handled it can be taken over by nearby areas like the face.
- **New neurons** are made in the hippocampus of many mammals throughout life. Whether adult humans make many new neurons there is still hotly debated. Two major studies in 2018 reached opposite answers.

Plasticity is strongest in childhood. Some skills have "sensitive periods". For example, learning to hear the sounds of a language is far easier in infancy. But adults stay plastic too.

London taxi drivers who learned the city's maze of streets were found to have larger rear hippocampi than control groups.

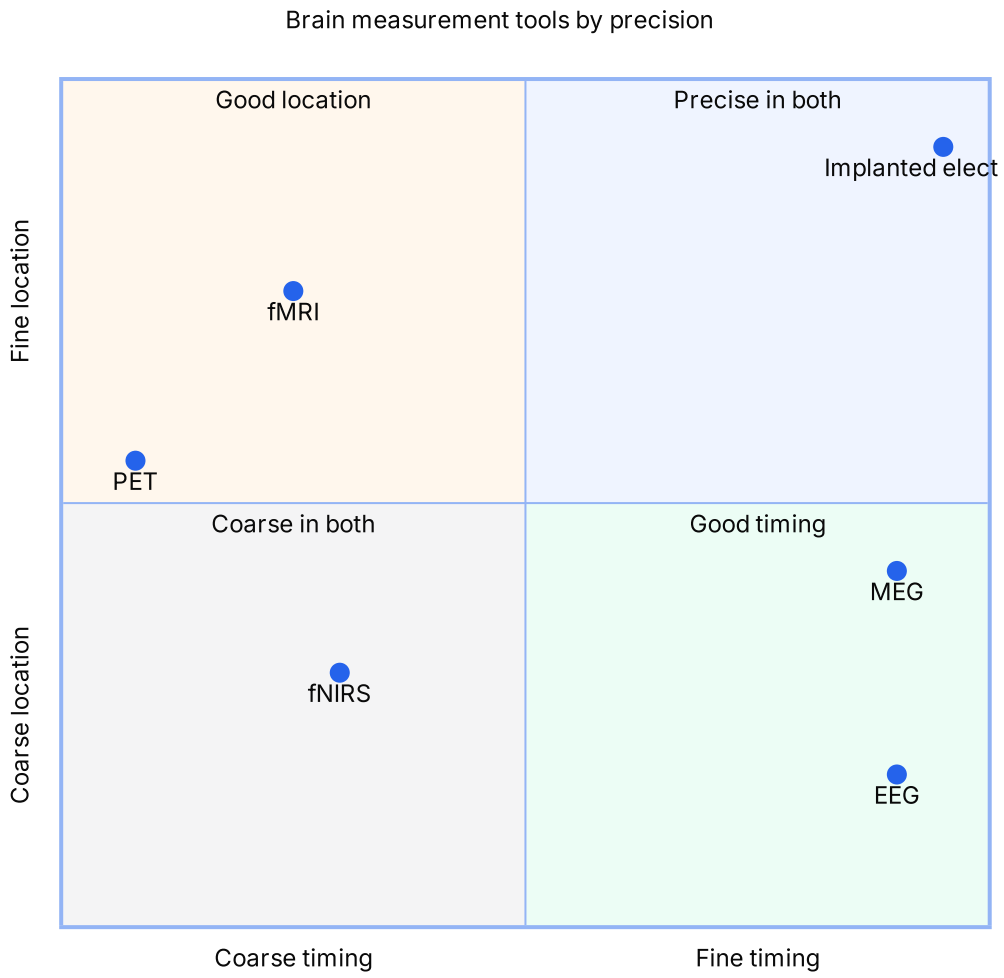
The energy budget

The brain is costly. It uses about 20 watts, less than a dim light bulb, but that is about a fifth of the body's resting energy. Most of this energy goes to signaling. Studies by David Attwell and Simon Laughlin estimated that most of the brain's signaling energy goes to restoring the balance of charged particles after spikes and synaptic activity. Because spikes are expensive, only a small fraction of neurons can be highly active at once. This forces the brain to use sparse, efficient codes.

The brain also has almost no fuel stores. It depends on a steady supply of glucose and oxygen from the blood. A few seconds without blood flow causes fainting. A few minutes causes lasting damage. This is one more reason why the brain's first job is to keep the body's budget in order.

How scientists watch the brain

No single tool shows everything. Each trades off how precisely it sees where activity happens against how precisely it sees when.


Brain measurement tools by precision
Good location
Precise in both
Implanted elect
fMRI
PET
Coarse in both
Good timing
MEG
fNIRS
EEG
Fine location
Coarse location
Coarse timing
Fine timing

TOOL	WHAT IT MEASURES	STRENGTHS	LIMITS
EEG	Electrical fields from the scalp	Millisecond timing, cheap, portable	Poor at locating sources, mostly sees the outer cortex
MEG	Magnetic fields from brain currents	Millisecond timing, better location than EEG	Large shielded room, expensive
fMRI	Blood oxygen changes that follow activity	Millimeter location, whole brain	Lags activity by seconds, person must lie still in a scanner
PET	Radioactive tracers for sugar use or specific receptors	Can measure chemistry like dopamine receptors	Radiation, slow, costly
fNIRS	Light shone through the skull to read blood oxygen	Portable, works while moving	Only the outer cortex, coarse
Lesion studies	Effects of damage from stroke or injury	Shows what a region is needed for	Damage is rarely neat, no control over where
Implanted electrodes	Spikes from single neurons	The finest detail	Only in surgery patients, tiny sample

An important caution goes with all of this. Brain activity in an area does not prove that area causes a behavior. A region may light up only because it is linked to the region that really matters. Lesion studies and methods that safely stimulate the brain, like transcranial magnetic stimulation, help test cause and effect.

Measurable signals

SIGNAL	WHAT IT TELLS YOU	TOOL
Brain rhythms such as alpha and theta waves	Alertness, sleep stage, relaxation	EEG headband or cap
Brain network activity at rest	Strength of default mode, salience and executive networks	fMRI
Daily cortisol curve	Stress system activity	Saliva samples at set times
Heart rate variability	Strength of the parasympathetic brake	Chest strap, wrist sensor
Skin conductance	Sympathetic arousal from sweat glands	Electrodes on fingers or wrist
Pupil size	Arousal and mental effort, linked to noradrenaline	Eye tracker
Thyroid and sex hormone levels	Energy level and hormonal state	Blood test
Brain structure	Size and thickness of regions, white matter paths	Structural MRI, diffusion MRI

Key takeaways

- The brain has about 86 billion neurons and a similar number of glia. Most of the neurons are in the cerebellum.
- Neurons talk with fast electrical spikes and chemical messengers at around 100 trillion synapses.
- Glutamate and GABA do most of the fast work. Dopamine, serotonin, noradrenaline and acetylcholine tune whole regions.
- Hormones such as cortisol work more slowly but reach the whole body. The HPA axis runs the stress response.
- The autonomic nervous system has a gas pedal and a brake. Heart rate variability gives a rough read of the brake.
- Default mode, salience and executive networks switch the mind between inner thought and outward focus.
- The brain keeps changing with experience all through life, most of all in childhood.
- Each brain measurement tool is a trade off between seeing when and seeing where.

SOURCES AND FURTHER READING

- Azevedo, F. A. C., et al. (2009). Equal numbers of neuronal and nonneuronal cells make the human brain an isometrically scaled-up primate brain. *Journal of Comparative Neurology*, 513(5), 532 to 541. https://doi.org/10.1002/cne.21974
- Herculano-Houzel, S. (2009). The human brain in numbers: a linearly scaled-up primate brain. *Frontiers in Human Neuroscience*, 3, 31. https://doi.org/10.3389/neuro.09.031.2009
- Attwell, D., and Laughlin, S. B. (2001). An energy budget for signaling in the grey matter of the brain. *Journal of Cerebral Blood Flow and Metabolism*, 21(10), 1133 to 1145. https://doi.org/10.1097/00004647-200110000-00001
- Raichle, M. E., et al. (2001). A default mode of brain function. *PNAS*, 98(2), 676 to 682. https://doi.org/10.1073/pnas.98.2.676
- Seeley, W. W., et al. (2007). Dissociable intrinsic connectivity networks for salience processing and executive control. *Journal of Neuroscience*, 27(9), 2349 to 2356. https://doi.org/10.1523/JNEUROSCI.5587-06.2007
- Menon, V. (2011). Large-scale brain networks and psychopathology: a unifying triple network model. *Trends in Cognitive Sciences*, 15(10), 483 to 506. https://doi.org/10.1016/j.tics.2011.08.003
- McEwen, B. S. (1998). Protective and damaging effects of stress mediators. *New England Journal of Medicine*, 338, 171 to 179. https://doi.org/10.1056/NEJM199801153380307

- Schultz, W., Dayan, P., and Montague, P. R. (1997). A neural substrate of prediction and reward. *Science*, 275(5306), 1593 to 1599. https://doi.org/10.1126/science.275.5306.1593

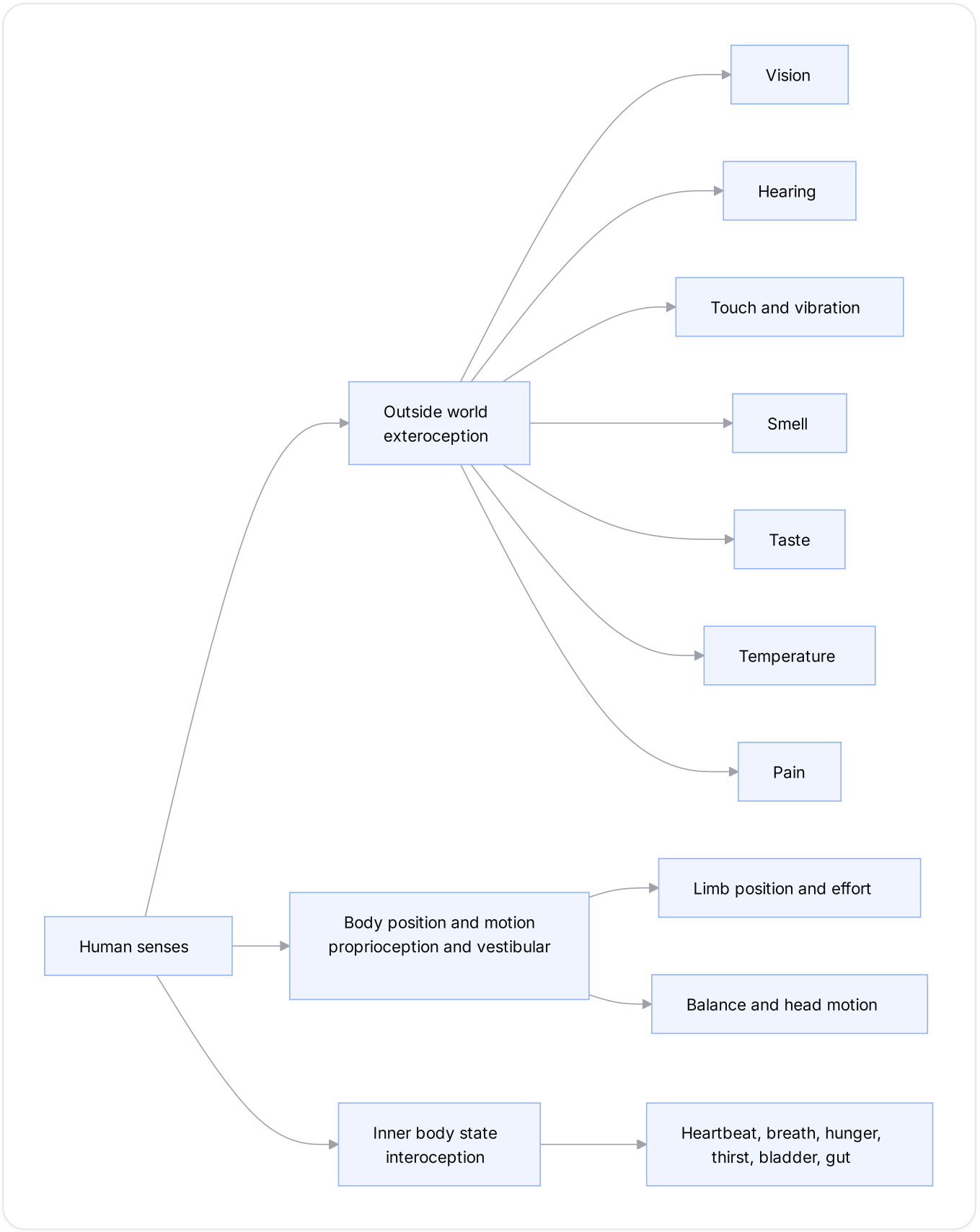
CHAPTER 03

Senses and Perception

Humans have far more than five senses. Besides sight, hearing, touch, smell and taste, we sense balance, the position of our limbs, heat and cold, pain and the inner state of our organs. Each sense turns one kind of energy into nerve signals, and each sends a very different amount of information. But perception is not a camera recording. The brain receives noisy, partial and delayed signals and makes its best guess about what is out there. This chapter covers each sense, how much each can carry, how the brain fills gaps and blends senses, how it builds a sense of time, and why no two people perceive the world quite the same way.

More than five senses

The "five senses" list goes back to Aristotle. Modern science counts more. There is no single agreed number, because it depends on how you split them. Some experts count around a dozen. Others count over twenty by treating each receptor type as its own sense. A useful approach is to group senses by what they track.



Every sense starts with a receptor. A receptor is a cell or protein that responds to one kind of energy. Light hits pigments in the eye. Sound waves bend tiny hairs in the inner ear. Molecules bind to proteins in the nose. In each case the receptor changes its electrical state,

and nerves carry the result to the brain. The brain never touches the world directly. It only gets these coded signals.

The senses one by one

Vision. The eye sees light from about 380 to 740 nanometers in wavelength, from violet to red. The retina at the back holds about 120 million rods for dim light and about 6 million cones for color and detail. Most people have three cone types, tuned to short, medium and long wavelengths. Every color you see comes from comparing those three. Sharp vision only comes from a tiny central spot called the fovea, about the size of your thumbnail at arm's length. The eyes jump about three times per second to point the fovea at new things. The feeling that the whole scene is sharp is built by the brain.

Hearing. A young ear hears from about 20 to 20,000 vibrations per second (hertz). The upper limit falls with age. Many adults over 50 cannot hear much above 12,000 to 14,000 hertz. The cochlea is a fluid filled coil in the inner ear. It holds about 3,500 inner hair cells, which do most of the hearing, plus about 12,000 outer hair cells that boost quiet sounds. Hearing is very fast. We can detect timing differences between the two ears of just a few millionths of a second. That is how we tell where a sound came from.

Touch. The skin has several kinds of touch receptors. Some sense steady pressure. Some sense vibration. Some sense skin stretch. Some sense light stroking. The fingertips and lips have the most receptors, which is why they are so sensitive. A special group of slow nerve fibers, called C tactile fibers, responds best to gentle stroking at about skin temperature. They seem tuned to caring touch from other people. In 2021 Ardem Patapoutian shared the Nobel Prize for finding the Piezo proteins, which turn pressure into nerve signals.

Smell. Humans have about 400 working types of smell receptor. Each odor activates a pattern across many of them, like a chord on a piano. A 2014 study claimed humans can tell apart more than one trillion smells. Other scientists showed that this number depends heavily on the math used, so treat it as debated. What is clear is that the human nose is much better than its old reputation. Smell is also the only sense that does not pass through the thalamus first. It has short links to the amygdala and hippocampus. This may be why a smell can bring back an old memory and a strong feeling so suddenly.

Taste. The tongue detects five agreed basic tastes: sweet, salty, sour, bitter and umami (savory). Fat and a few others are candidates still under study. Most of what we call "flavor" actually comes from smell. Air from food in your mouth rises to the nose from behind. That is why food tastes flat when you have a cold.

Balance. The vestibular system sits in the inner ear next to the cochlea. Three fluid filled loops sense head rotation. Two small sacs sense gravity and straight line motion. You rarely notice this sense until it fails. Motion sickness happens when your eyes and your inner ear disagree about how you are moving.

Proprioception. This is the sense of where your limbs are and how hard your muscles are working. Sensors in muscles, tendons and joints report all the time. Close your eyes and touch your nose. Proprioception makes that possible. People who lose it, which is very rare, must watch their limbs constantly to move.

Temperature. Separate nerve endings sense warmth and cold. David Julius shared the 2021 Nobel Prize for finding the receptors involved. One, called TRPV1, responds to heat and to capsaicin in chili. Another, TRPM8, responds to cold and to menthol. That is why chili feels hot and mint feels cool, even at room temperature.

Pain. Pain receptors, called nociceptors, respond to damage or the threat of it. But pain is not just a signal from the body. The brain decides how much it hurts. Soldiers and athletes sometimes feel little pain from serious injuries in the moment. People with chronic pain can feel strong pain with no clear damage. Fear, attention and expectation all turn pain up or down.

Interoception. This is the sense of the body's inner state. It covers heartbeat, breathing, hunger, thirst, a full bladder, nausea and more. Signals travel mainly through the vagus nerve and spinal pathways to the insula, a part of the cortex folded deep in the side of the brain. The neuroanatomist Bud Craig argued that the insula builds a "feeling of the body" that underlies emotion. People differ a lot in how well they sense their own heartbeat. Chapter 7 shows how this links to emotion.

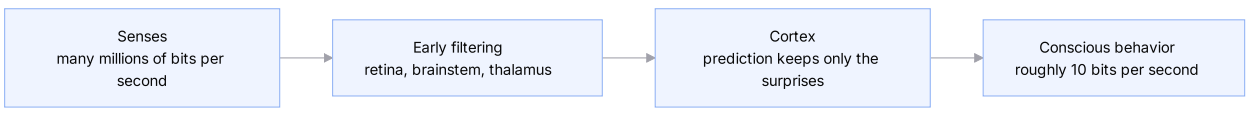
Bandwidth: how much each sense carries

How much information does each sense send to the brain? This is hard to measure, and the numbers below are rough. They count nerve fibers and estimate how much each can carry. Vision clearly dominates. About a third or more of the cortex is involved in seeing in some way.

SENSE	ROUGH RECEPTOR COUNT	ROUGH NERVE FIBERS TO BRAIN	NOTES ON CAPACITY
Vision	About 126 million rods and cones per eye	About 1 million per eye	One estimate puts each retina's output near 10 million bits per second
Hearing	About 3,500 inner hair cells per ear	About 30,000 per ear	Very fine timing, much lower total volume than vision
Touch	Many thousands per fingertip area	Over a million across the body	Fingertips can feel ridges smaller than a hair's width
Smell	About 400 receptor types, millions of cells	Several million small fibers	Many smells at once are hard to separate
Taste	About 5 basic qualities	Small	Flavor relies mostly on smell
Balance	Five organs per ear	About 20,000 per ear	Mostly unconscious
Interoception	Spread across all organs	Vagus nerve has about 100,000 fibers per side	Mostly unconscious

The 10 million bits per second for the retina comes from a 2006 study by Kristin Koch and colleagues. They measured guinea pig retinas and scaled up to humans. Treat it as an order of magnitude, not an exact figure.

The striking thing is how much of this never reaches awareness. A 2024 paper by Jieyu Zheng and Markus Meister argued that conscious human behavior, such as typing or speaking or playing a game, runs at only about 10 bits per second. The senses deliver many millions of bits per second. So the brain throws away or compresses almost all of it. The exact figures are debated, but the gap is huge on any account.

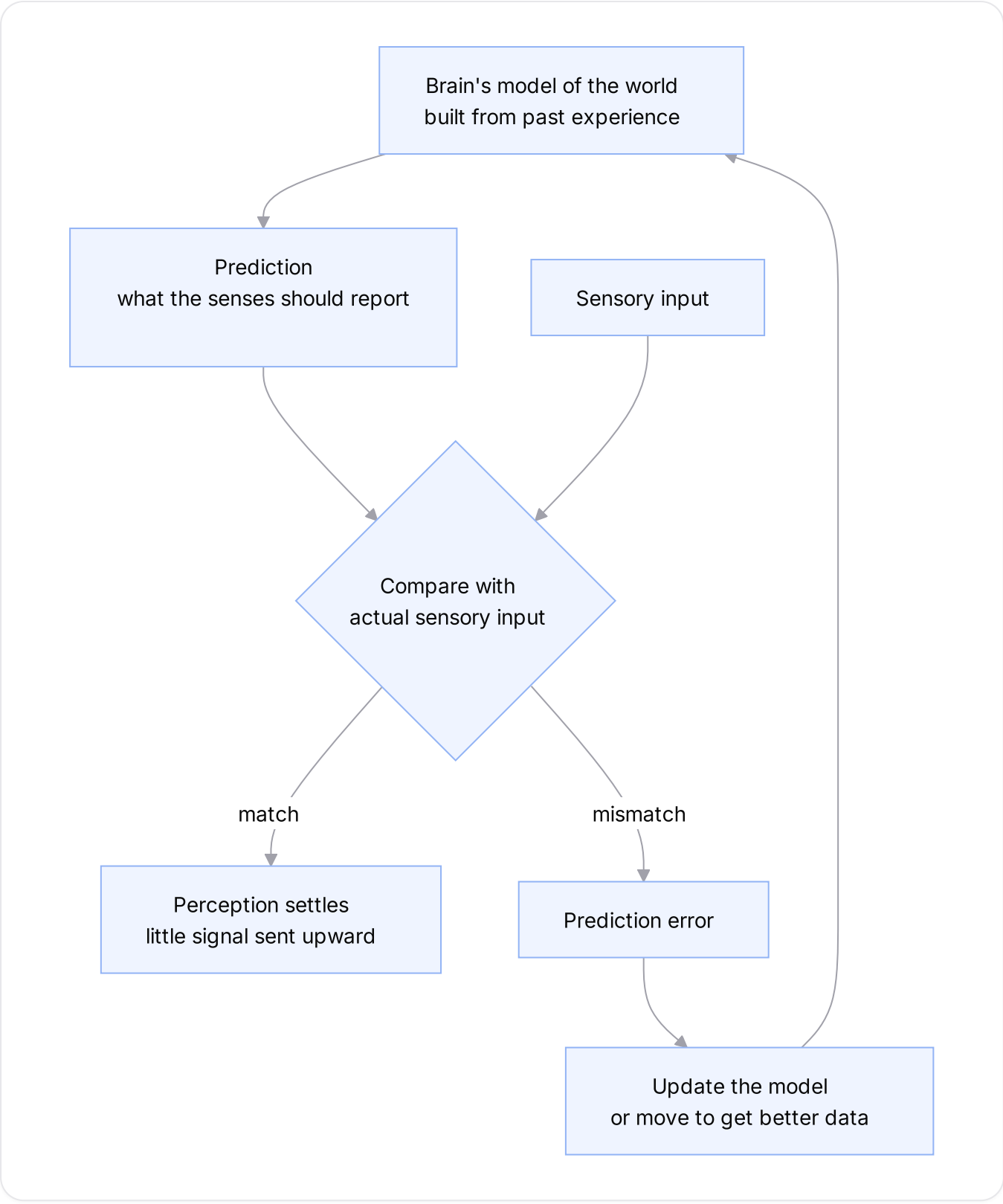


This funnel is a picture of scale, not a wiring diagram. The point is that what we notice is a tiny, chosen slice of what our senses take in.

Perception as the brain's best guess

Here is a simple puzzle. The image on your retina is flat, upside down, blurry at the edges, and has a hole where the optic nerve leaves the eye. Yet you see a sharp, stable, three dimensional world with no hole. How?

The answer is that perception is a guess. In 1867 Hermann von Helmholtz called it "unconscious inference". In 1980 the psychologist Richard Gregory called perceptions "hypotheses". Today many scientists describe the brain as a prediction machine. This idea is called predictive processing.



The idea works like this. The brain holds a model of what is likely out there. It sends predictions down to the sensory areas. Mostly, only the surprises, called prediction errors, travel back up. If the input matches the guess, little needs to change. If not, the model updates. Or you move your eyes, head or hand to get better data.

This view explains many everyday facts:

- **Filling in.** You do not see the blind spot in each eye. The brain fills it with the surrounding pattern.
- **Illusions.** In the hollow face illusion, a mask seen from behind looks like it bulges out. Your brain expects faces to be convex and that belief beats the evidence.
- **Expectation shapes what you see.** A blurry blob looks like a cup in a kitchen and a hair dryer in a bathroom.
- **Placebo pain relief.** If you expect a pill to help, the brain's prediction can reduce how much pain you feel.

Predictive processing is a powerful and popular framework. But how far it explains everything is debated. Some scientists see it as a broad theory of the whole brain. Others see it as a useful story that is hard to test in detail. The simpler claim, that perception mixes incoming signals with prior expectations, is very well supported.

Multisensory integration

The senses do not work alone. The brain blends them. In the McGurk effect, you hear a voice saying "ba" while watching lips say "ga". Most people then hear "da", a blend that neither sense reported. A ventriloquist's voice seems to come from the dummy because vision pulls the location of the sound.

In 2002 Marc Ernst and Martin Banks showed how this blending works. People judged the height of a bar by looking and by touching it. The brain weighted each sense by how reliable it was. When they made vision blurry, people relied more on touch. The result was close to the best possible combination a statistician would compute. This kind of reliability weighting shows up again and again.

The brain also needs to decide which signals belong together. Sights and sounds that arrive within roughly a tenth to a quarter of a second are often bound into one event. This window is wider in children and differs between people.

Time perception

There is no single sense organ for time. Yet we judge durations, rhythms and order all the time. Several brain systems seem to help. These include the cerebellum for short intervals, the basal ganglia for intervals of seconds, and the insula for felt duration.

Time perception is easy to bend:

- **Lag.** Our experience of now is slightly behind the world. Signals take time to process, so the brain lives a fraction of a second in the past and partly predicts the present.
- **The present moment.** What feels like "now" seems to span about 2 to 3 seconds. Many rhythms in speech, music and movement fit this window.
- **Fear slows time, at least in memory.** People who fell during a free fall study by David Eagleman said the fall felt longer. But they could not see faster during it. The stretch seems to be in how the memory was stored.
- **Busy versus boring.** Time drags when you are bored and waiting. But looking back, a busy week feels longer than an empty one, because it left more memories.

Why perception differs between people

People do not share one standard perceptual world. Differences come from genes, body, experience and culture.

DIFFERENCE	WHAT IT IS	HOW COMMON	NOTES
Color vision deficiency	One cone type missing or shifted, usually red or green	About 8 percent of men and 0.5 percent of women of Northern European descent	Gene is on the X chromosome, so men are affected more
Tetrachromacy	A possible fourth cone type	Carried by some women. Clear behavioral evidence of extra color vision is rare	Debated how often it changes what people see
Supertasters	Extra sensitivity to bitter tastes, more taste buds	About 25 percent of people in some studies	Linked partly to the TAS2R38 gene. Often dislike bitter greens and strong coffee
Synesthesia	One sense triggers another, such as letters with colors	About 4 percent for all types	Stable over a lifetime, runs in families
Aphantasia	No voluntary mental imagery, an "empty mind's eye"	About 1 percent extreme, 2 to 4 percent with weak imagery	Named in 2015. Prevalence estimates vary
Hyperphantasia	Extremely vivid imagery	About 3 percent in some surveys	The other end of the same scale
Absolute pitch	Naming a note with no reference	Rare, often quoted as about 1 in 10,000 in Western samples	More common with early music training and tonal languages

Beyond these named conditions, there is wide ordinary variation. People differ in how well they sense their heartbeat, how much pain they feel from the same stimulus, and how loud a sound must be to bother them. Even the famous 2015 photo of "the dress" showed this. Some people saw it as blue and black, others as white and gold. The difference seems to come from what each brain assumed about the lighting.

Experience also tunes perception. A wine expert learns to separate flavors a novice cannot. Babies can hear the sound differences of every language. By their first birthday they have mostly tuned to the sounds of their own. Culture can shape where we look in a scene and which colors we name.

The key lesson is this. Each person's perception is a set of guesses shaped by their own body, genes and past. Two people can stand in the same room and live in slightly different worlds.

Measurable signals

SIGNAL	WHAT IT SHOWS	TOOL
Visual acuity and color vision	Basic eye function, color deficiency	Eye chart, Ishihara plates
Hearing thresholds by frequency	Hearing range and loss	Audiometry
Eye movements and pupil size	Where attention goes, mental effort	Eye tracker
Smell identification	Range and loss of smell	Scratch and sniff tests
Bitter taste sensitivity	Supertaster status	PROP taste strips, gene test
Heartbeat detection accuracy	Interoceptive skill	Heartbeat counting or tapping tasks
Pain threshold	Sensitivity to pain	Quantitative sensory testing
Vividness of mental imagery	Aphantasia to hyperphantasia	VVIQ questionnaire
Audio visual binding window	How tightly senses are linked in time	Simultaneity judgment tasks
Balance	Vestibular function	Balance plate, head impulse test

Key takeaways

- Humans have many more than five senses, including balance, limb position, temperature, pain and the sense of the inner body.
- Every sense turns energy into nerve signals. The brain only ever gets these signals, never the world itself.
- Vision carries by far the most information. Yet conscious behavior seems to run at only about 10 bits per second.
- Perception is a best guess that blends incoming signals with expectations. Illusions show the guess at work.
- The brain combines senses by trusting the more reliable one more.
- Our sense of time is built, not read off a clock, and stretches with emotion and attention.
- Genes, bodies and experience make each person's perception a little different.

SOURCES AND FURTHER READING

- Gregory, R. L. (1980). Perceptions as hypotheses. *Philosophical Transactions of the Royal Society B*, 290, 181 to 197. https://doi.org/10.1098/rstb.1980.0090
- Ernst, M. O., and Banks, M. S. (2002). Humans integrate visual and haptic information in a statistically optimal fashion. *Nature*, 415, 429 to 433. https://doi.org/10.1038/415429a
- Clark, A. (2013). Whatever next? Predictive brains, situated agents, and the future of cognitive science. *Behavioral and Brain Sciences*, 36(3), 181 to 204. https://doi.org/10.1017/S0140525X12000477
- Craig, A. D. (2002). How do you feel? Interoception: the sense of the physiological condition of the body. *Nature Reviews Neuroscience*, 3, 655 to 666. https://doi.org/10.1038/nrn894
- Koch, K., et al. (2006). How much the eye tells the brain. *Current Biology*, 16(14), 1428 to 1434. https://doi.org/10.1016/j.cub.2006.05.056
- Zheng, J., and Meister, M. (2025). The unbearable slowness of being: Why do we live at 10 bits/s? *Neuron*, 113(2), 192 to 204. https://doi.org/10.1016/j.neuron.2024.11.008
- Bushdid, C., et al. (2014). Humans can discriminate more than 1 trillion olfactory stimuli. *Science*, 343, 1370 to 1372. https://doi.org/10.1126/science.1249168. See the critique by Meister, M. (2015), *eLife*, https://doi.org/10.7554/eLife.07865
- Simner, J., et al. (2006). Synaesthesia: the prevalence of atypical cross-modal experiences. *Perception*, 35(8), 1024 to 1033. https://doi.org/10.1068/p5469. On aphantasia see Zeman, A., et al. (2015), *Cortex*, https://doi.org/10.1016/j.cortex.2015.05.019

CHAPTER 04

Attention, Consciousness and the Self

Your brain takes in far more than you ever notice. Attention is the filter that picks a small slice of the world for deeper work. Consciousness is the felt experience of that slice. The self is the story and the body feeling that tie all of it to "me". This chapter explains how attention works and where it fails. It walks through the main scientific theories of consciousness and the big 2025 test that put two of them head to head. It then looks at sleep, dreams and anesthesia as natural experiments in switching experience off and on. It ends with the sense of self, split brain patients and the long fight over free will.

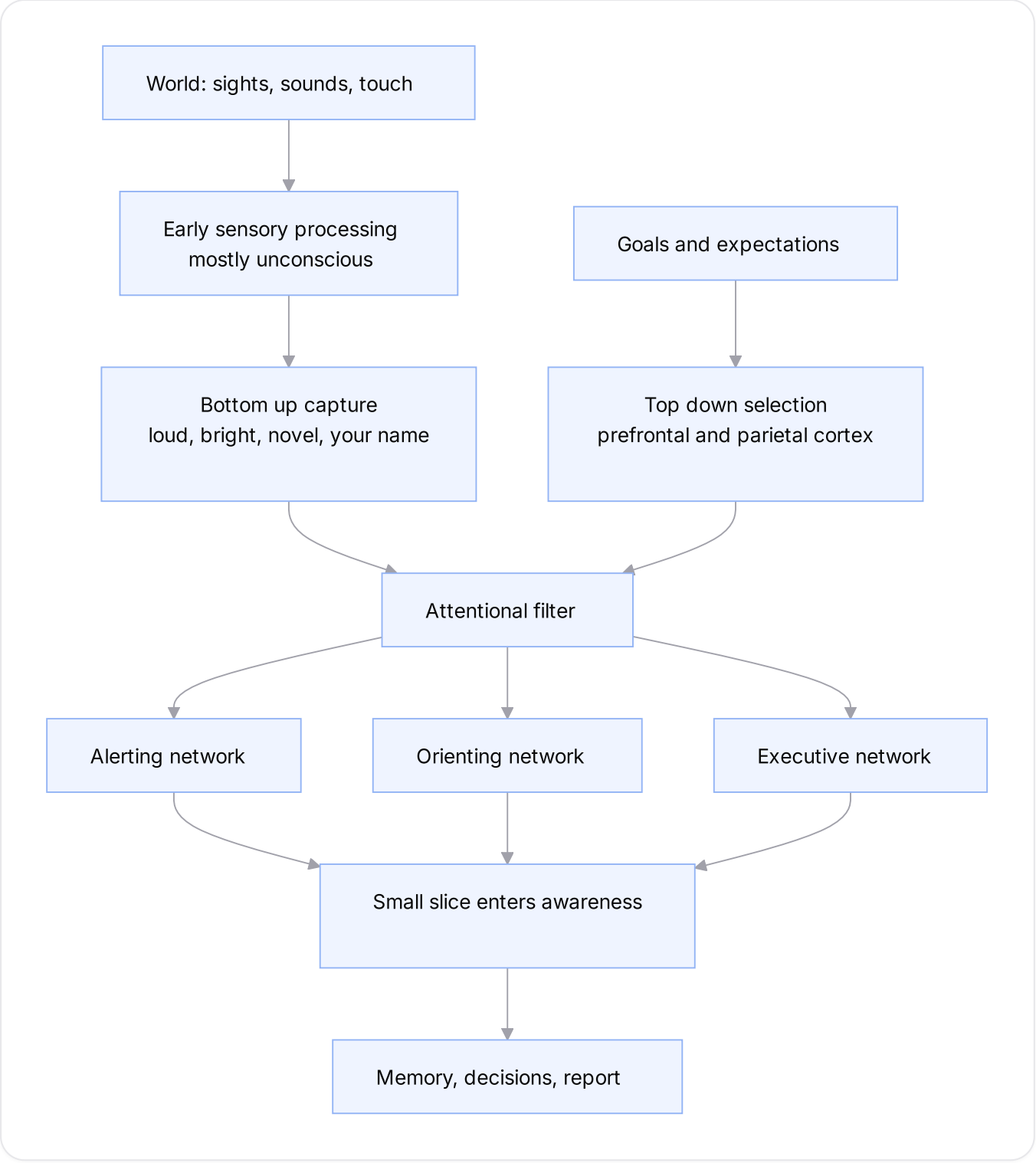
Attention: the spotlight with a budget

In a busy café you can follow your friend's words and ignore the rest. Then someone at the next table says your name and you turn at once. Those two moments show the two drivers of attention.

Top down attention is the kind you choose. You decide what matters and your brain boosts it. Reading this sentence while the radio plays is top down. **Bottom up attention** is grabbed by the world. A loud bang or a flash of movement pulls you in without asking. Your own name works the same way because it is so important to you.

Selective attention means picking one stream and muting others. **Divided attention** means following two at once. It mostly fails when both tasks need the same mental resources. You can walk and talk. You cannot read an email and follow a hard conversation. What feels like multitasking is usually fast switching. Each switch costs time and adds errors.

Michael Posner proposed that attention is not one thing but three linked brain networks. The **alerting** network keeps you ready. It leans on the brainstem chemical noradrenaline. The **orienting** network moves your focus to a place or object. It uses areas in the parietal lobe near the top back of the head and the frontal eye fields. The **executive** network settles conflicts. When you must name the ink color of the word "RED" printed in blue, this network holds back the urge to read the word. It relies on the anterior cingulate and the prefrontal cortex. A simple computer task called the Attention Network Test can measure all three in about 20 minutes.



The limits of awareness

In a famous 1999 study, Daniel Simons and Christopher Chabris asked people to count basketball passes in a short video. Midway a person in a gorilla suit walked through the scene and thumped their chest. About half the viewers never saw the gorilla. This is **inattentional blindness**. When attention is busy, even big and strange things can pass unseen.

A cousin effect is **change blindness**. If a scene flickers or you look away, large changes can go unnoticed. In one field study a stranger asking for directions was swapped for another person. Many helpers never noticed.

So the rich, complete world we seem to see is partly an illusion. We hold a detailed picture of only a small region at any moment. The brain fills in the rest from expectation. Working memory, the mental notepad for what you are thinking about right now, holds only about four chunks at once.

Unconscious processing

Much of what the brain does never reaches awareness. Some of the clearest evidence comes from patients with **blindsight**. Damage to their primary visual cortex leaves them blind in part of their visual field. Yet when forced to guess, they can point to objects there or tell which way a line is tilted far better than chance. Parts of the visual system that skip the damaged area still work. They just do not produce experience.

In healthy people, researchers use **masking**. A word flashes for a few hundredths of a second and is then covered by a pattern. People report seeing nothing. Still, the hidden word can speed up reading of a related word. This is **priming**. The effects are real but small and brief. Claims that hidden messages steer what people buy or vote for have mostly failed to replicate.

So the brain does a huge amount of quiet work. Consciousness seems to come in when information must be held, combined, reported or used flexibly.

Theories of consciousness

Why does some brain activity come with experience and some does not? Several major theories compete. Each picks a different feature of the brain as the key.

THEORY	CORE IDEA IN PLAIN WORDS	WHERE IT LOOKS IN THE BRAIN	MAIN CRITICS SAY
Global workspace (Baars, Dehaene)	Content becomes conscious when it is broadcast widely so many brain systems can use it. Think of a stage lit for the whole theater.	Prefrontal and parietal networks. A sudden "ignition" of activity.	It may explain access and report but not the felt quality of experience.
Integrated information (Tononi)	Consciousness is how much a system's parts form one unified whole that is more than its pieces. Measured as "phi".	Mostly posterior cortex at the back of the brain.	Phi cannot be computed for real brains. Some say it implies odd things are conscious.
Higher order (Rosenthal, Lau, LeDoux)	A state is conscious when the brain also represents that it is in that state. A thought about a thought.	Prefrontal cortex.	Hard to test directly. Patients with prefrontal damage still seem conscious.
Predictive processing and the "beast machine" (Seth)	The brain constantly guesses what causes its inputs. Experience is a controlled guess. Body feelings come from guesses about the body's inner state, rooted in staying alive.	Widespread loops between higher and lower areas, including body signal regions like the insula.	It is a broad framework. It may explain too much to be easily proven wrong.
Attention schema (Graziano)	The brain builds a simple model of its own attention. That model is what we describe as "awareness".	Temporoparietal junction and related areas.	Critics say it explains why we believe we are conscious rather than consciousness itself.

A useful split is between **access** (information is available to use and report) and **experience** (it feels like something). Workspace and higher order theories lean toward access. Integrated information theory aims at experience.

The 2025 COGITATE test: neither theory won

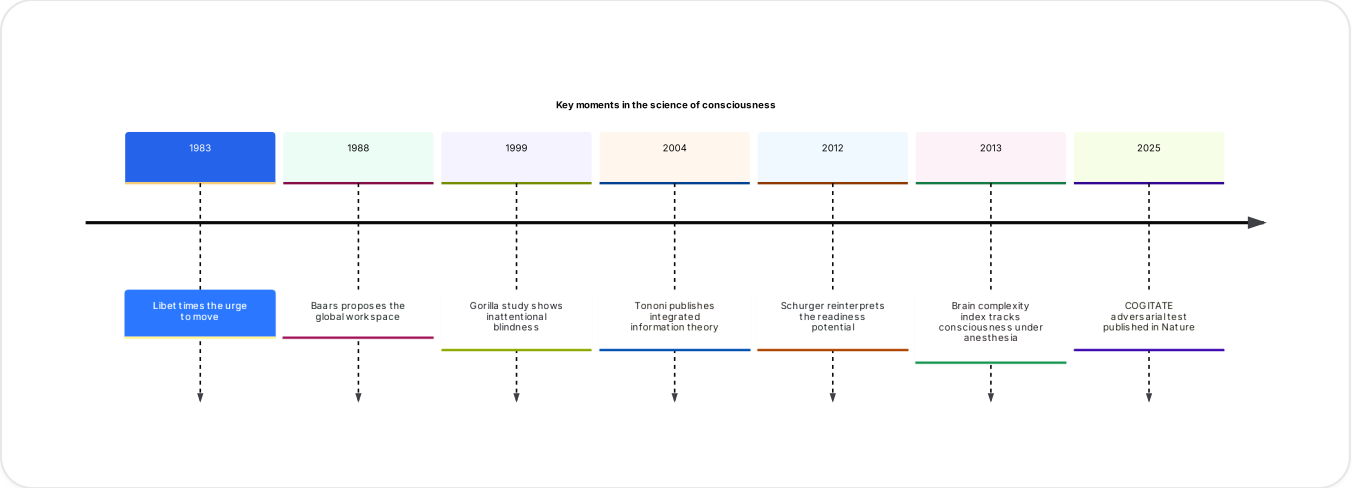
In consciousness research each camp mostly ran its own studies. So the COGITATE Consortium set up an **adversarial collaboration**. Leaders of global workspace theory and integrated information theory agreed in advance on what each theory predicted. A neutral team then ran the tests and registered the plan publicly before collecting data.

About 250 people took part across several labs. They viewed faces, objects, letters and meaningless symbols for different lengths of time. The team recorded brain activity with three tools. These were fMRI, which tracks blood flow, MEG, which tracks tiny magnetic fields, and electrodes placed inside the brains of epilepsy patients for medical reasons.

The results were published in Nature in 2025. Both theories took hits.

- Integrated information theory predicted that the back of the brain would stay in sustained synchrony for as long as an image was seen. That lasting synchrony did not show up as predicted.
- Global workspace theory predicted a burst of "ignition" in the prefrontal cortex when an image disappeared, marking an update of the conscious scene. That burst was largely absent. The prefrontal cortex also held only some of the details of what people saw.
- Some predictions of each theory did fit. Information about what people saw was strongly present in the back of the brain, as integrated information theory expected. Some content was readable from the front of the brain, as workspace theory expected.

The fair summary is that neither theory fully won. The study did show that these theories can make risky predictions and fail them. Both camps still argue over what the results mean.



Sleep, dreams and anesthesia

Every night you lose consciousness and get it back. This makes sleep the most common natural test of the theories.

Sleep runs in cycles of roughly 90 minutes. Each cycle moves through lighter and deeper **non REM sleep** and then **REM sleep**, named for rapid eye movements under the lids. Experience fades most in deep non REM sleep. Brain waves become large and slow. REM sleep looks much more like waking on an EEG. It brings the most vivid, story like dreams while the big muscles are paralyzed. But people woken from any stage sometimes report dreams.

Dreams show that the brain can build a full world with no outside input. This fits predictive theories. In sleep the brain keeps guessing but the senses no longer correct it.

General anesthesia is a deliberate switch. Drugs like propofol cut off experience in minutes. A clever test measures how well the brain can still hold a complex conversation with itself. Researchers send a brief magnetic pulse into the cortex with TMS and record the echo with EEG. In awake people and in dreaming sleep, the echo is complex and spreads in rich patterns. In deep sleep and under most anesthetics it is simple and local. This gives the **perturbational complexity index**. It has flagged some unresponsive brain injury patients as likely conscious. Ketamine is a telling exception. People under it stop responding yet often report vivid dreams, and the echo stays complex.

The sense of self

The self is not one thing. Scientists usually split it into layers.

The **bodily self** is the feeling that this body is mine and I am located inside it. It is built moment by moment from vision, touch, balance and signals from inside the body. The **rubber hand illusion** shows how flexible it is. Hide a person's real hand. Put a rubber hand in front of

them. Stroke both with brushes at the same time. Within a minute or two many people feel the rubber hand is their own. Similar tricks with video goggles can make people feel they are standing outside their body.

The **sense of agency** is the feeling "I did that". It arises when the brain's prediction of what an action will cause matches what actually happens. This is why you cannot tickle yourself. Your brain predicted the touch and turned its intensity down. When this matching goes wrong, as in some cases of schizophrenia, people may feel their own thoughts or actions are controlled from outside.

The **narrative self** is the life story you tell about who you are. It draws on autobiographical memory (Chapter 5) and is partly rebuilt each time you tell it.

Split brain: one skull, two streams

Since the 1960s some people with severe epilepsy had surgery that cut the corpus callosum. That is the thick bundle of about 200 million fibers that joins the two halves of the brain. Roger Sperry and Michael Gazzaniga then studied them.

In daily life these patients seem normal. In the lab the halves can be tested apart. Show a picture only to the right hemisphere and the patient often says they saw nothing. That is because speech sits mostly in the left. Yet their left hand, run by the right hemisphere, can pick out the matching object. Ask the left hemisphere why the hand chose it and it will often invent a confident but wrong reason. Gazzaniga called this left side story maker the **interpreter**.

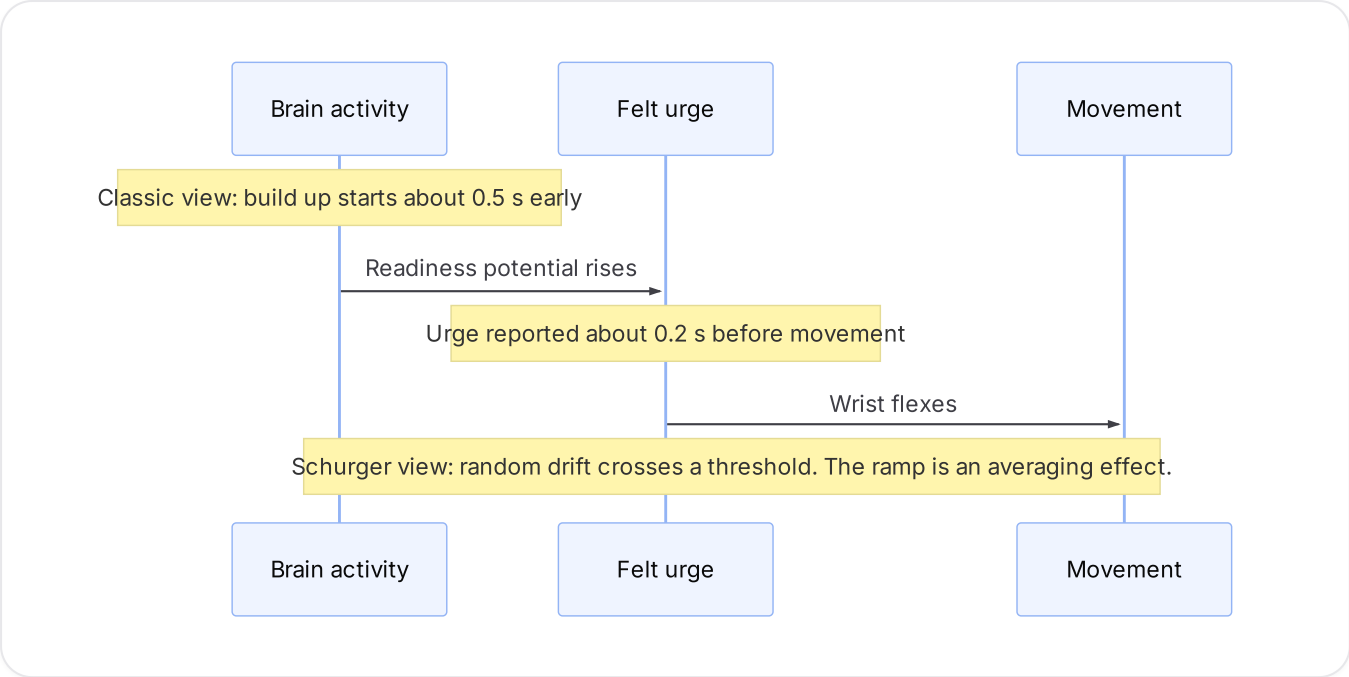
Healthy people do this too. We make up reasons for choices whose real causes we cannot see. Whether split brain patients have two streams of consciousness is still debated. Some newer studies suggest the split is less complete than classic accounts claimed.

Free will: what the brain timing shows

In 1983 Benjamin Libet asked people to flex their wrist whenever they felt like it. They watched a fast clock and noted when they first felt the urge. EEG showed a slow build up of brain activity called the **readiness potential**. It began several hundred milliseconds before people said they felt the urge. Many read this as proof that the brain "decides" before you do.

In 2012 Aaron Schurger and colleagues offered a different reading. They argued the readiness potential may be mostly background noise in the brain drifting up and down. A movement happens when that drift happens to cross a threshold. Averaging many trials lined

up at the moment of movement then creates a ramp that looks like a plan. On this view the ramp is not a hidden decision at all. Later studies have backed parts of this account.



So the Libet results do not settle free will. They concern simple, unplanned flicks of the wrist. They say little about big choices made over days, like taking a job. Whether free will needs anything beyond a brain that weighs reasons and acts is a question for philosophy. The readiness potential alone cannot answer it.

Measurable signals

WHAT	HOW IT COULD BE MEASURED IN A LIVING PERSON
Alerting, orienting and executive attention	Attention Network Test (reaction times on a computer)
Where attention goes	Eye tracking. Pupil size as a rough index of effort and arousal
Level of consciousness	EEG. TMS with EEG to compute the perturbational complexity index
Sleep stages and dream periods	Polysomnography (EEG, eye and muscle sensors). Home headbands at lower accuracy
Content of conscious perception	fMRI or MEG decoding of seen categories, in lab settings only
Bodily self flexibility	Rubber hand illusion questionnaires and how far the felt hand position drifts
Sense of agency	"Intentional binding" timing tasks

Key takeaways

- Attention is a limited filter driven by both goals (top down) and the world (bottom up). It runs on at least three linked brain networks.
- We notice far less than we think. Inattentional and change blindness are normal, not flaws.
- Most brain processing is unconscious. Consciousness seems tied to holding and sharing information widely.
- Leading theories disagree on what makes experience. The 2025 COGITATE test challenged both global workspace and integrated information theory. Neither won.
- Sleep, dreams and anesthesia show that experience can fade, return or run with no outside input.
- The self has layers: body, agency and story. All are built by the brain and can be fooled.
- Libet style findings do not disprove free will. The readiness potential may be a side effect of averaging noise.

SOURCES AND FURTHER READING

- Cogitate Consortium et al. (2025). Adversarial testing of global neuronal workspace and integrated information theories of consciousness. *Nature*. https://doi.org/10.1038/s41586-025-08888-1
- Seth, A. K. and Bayne, T. (2022). Theories of consciousness. *Nature Reviews Neuroscience*. https://doi.org/10.1038/s41583-022-00587-4
- Simons, D. J. and Chabris, C. F. (1999). Gorillas in our midst. *Perception*. https://doi.org/10.1068/p281059
- Posner, M. I. and Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience*. https://doi.org/10.1146/annurev.ne.13.030190.000325
- Schurger, A., Sitt, J. D. and Dehaene, S. (2012). An accumulator model for spontaneous neural activity prior to self-initiated movement. *PNAS*. https://doi.org/10.1073/pnas.1210467109
- Casali, A. G. et al. (2013). A theoretically based index of consciousness independent of sensory processing and behavior. *Science Translational Medicine*. https://doi.org/10.1126/scitranslmed.3006294
- Gazzaniga, M. S. (2005). Forty-five years of split-brain research and still going strong. *Nature Reviews Neuroscience*. https://doi.org/10.1038/nrn1723
- Botvinick, M. and Cohen, J. (1998). Rubber hands "feel" touch that eyes see. *Nature*. https://doi.org/10.1038/35784

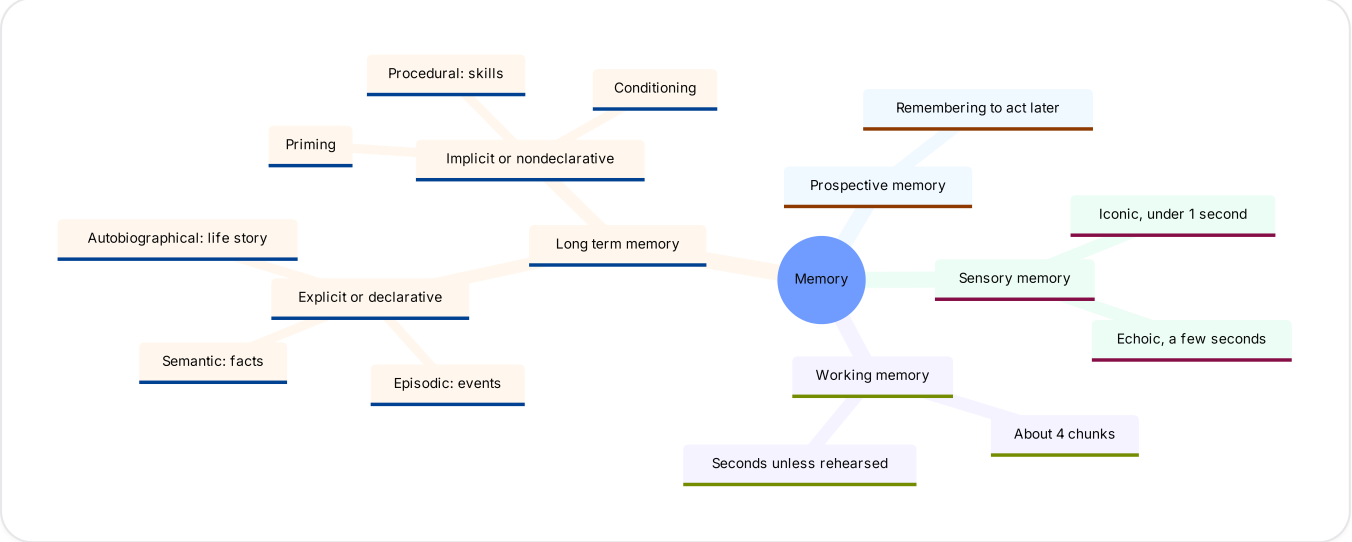
CHAPTER 05

Memory

Memory is not a video archive. It is a living system that keeps changing what it stores. This chapter sorts memory into its main types and follows one memory from the first moment to years later. It shows which brain parts do the work and what a memory trace looks like in cells. It explains why forgetting is useful and how false memories form. It covers the strong link with emotion and how memory changes from infancy to old age. It looks at people with extraordinary memory and people who lost theirs. It ends with how memory builds the sense of who we are.

The many kinds of memory

Memory includes recalling a birthday, riding a bike, feeling nervous in a dentist's chair and remembering to buy milk. These rely on different systems that can fail on their own.



Sensory memory holds a raw copy of what you just saw or heard. A visual trace fades in under a second. A sound trace lasts a few seconds. That is why you can "replay" what someone just said when you were not quite listening. **Working memory** is the mental notepad that holds a phone number while you dial it.

Long term memory splits into two families. **Explicit** memory is what you can consciously bring to mind. It includes **episodic** memory for events like your last birthday dinner and **semantic** memory for facts like the capital of Japan. **Autobiographical** memory blends both

into your life story. **Implicit** memory shows up in behavior without needing conscious recall. It includes **procedural** memory for skills like typing, **priming** where past exposure makes something easier to process, and **conditioning** where you link a cue with an outcome. A song that makes you feel sad before you know why is often conditioning at work.

Prospective memory is remembering to act in the future, like taking a pill. It leans heavily on cues in the environment.

The life of a memory

A memory goes through stages. Each stage can change it.

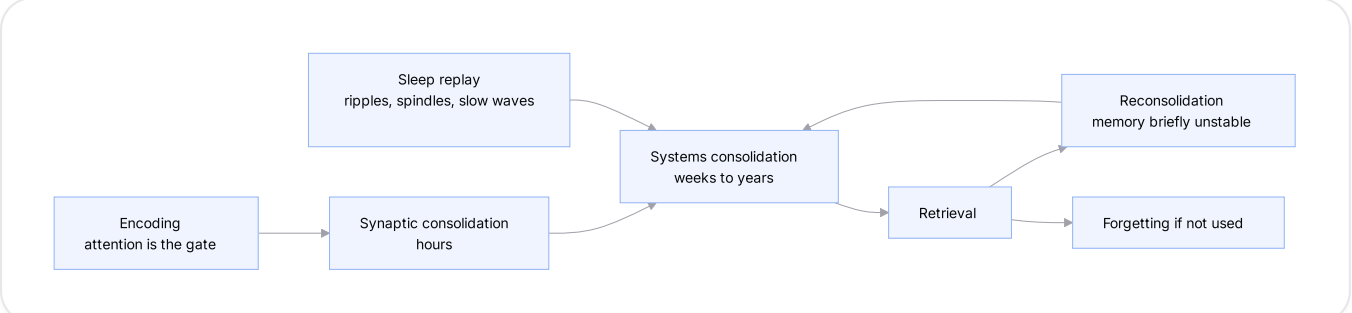
Encoding turns experience into a brain trace. Attention is the gate. Deep processing helps. Thinking about what a word means stores it better than noting its font.

Consolidation makes a fragile trace stable. In the first hours, synapses (the contact points between neurons) are strengthened through new proteins. A blow to the head or certain drugs during this window can wipe out recent memories.

Systems consolidation is slower. It takes weeks to years. At first the hippocampus acts as an index that links the scattered pieces of an event stored across the cortex. Over time the cortex links the pieces directly. Then the memory depends less on the hippocampus. Whether vivid episodic detail ever becomes fully independent of the hippocampus is debated. Some researchers argue that rich detail always needs it while the gist moves to the cortex.

Sleep replay drives much of this. During deep sleep the hippocampus replays the day's patterns in fast bursts called sharp wave ripples. These line up with slow waves and spindles in the cortex, which seems to help move memories into long term storage. People who sleep after learning remember more than people who stay awake.

Retrieval and reconsolidation come last. Recalling a memory does not just read it. It can make the memory briefly unstable again. The brain then saves it once more. This is **reconsolidation**. Each recall is a chance to update a memory. It is also a chance to distort it.



Where memory lives in the brain

STRUCTURE	MAIN JOB IN MEMORY	WHAT HAPPENS WHEN IT IS DAMAGED
Hippocampus	Binds the parts of events and places. Forms new explicit memories.	Cannot form new event and fact memories. Old ones are partly spared.
Neocortex	Long term store of facts, meanings and the pieces of events.	Loss depends on area. Semantic dementia erases word and object meanings.
Prefrontal cortex	Working memory. Organizing and checking recall.	Poor source memory. More false recall and confabulation.
Amygdala	Tags events with emotional weight. Fear learning.	Weaker boost of emotional memories. Impaired fear conditioning.
Basal ganglia	Habits and skill learning through reward.	Trouble learning routines, as in Parkinson's disease.
Cerebellum	Timing and fine tuning of movements. Simple conditioned reflexes like eye blinks.	Clumsy movements. Poor learning of timed reflexes.

Engrams and LTP: memory in cells

An **engram** is the physical trace of a memory. Only recently could scientists see one. In mice, researchers tag the neurons that fire during a fearful event. Days later they switch on just those neurons with light, a method called optogenetics. The mouse freezes in fear in a safe place. Switching them off can block the memory. In one study researchers even created a false fear memory by activating an old place engram while giving a mild shock.

The leading cell mechanism is **long term potentiation (LTP)**. Tim Bliss and Terje Lømo found it in 1973 in the rabbit hippocampus. When two neurons fire together strongly, the link between them gets stronger and stays strong. This is often summed up as "cells that fire together wire together". The reverse, **long term depression**, weakens links. Together they let experience reshape brain circuits. LTP is the best candidate for how memories are written. The exact rules are still being worked out.

Forgetting and why it is useful

In the 1880s Hermann Ebbinghaus memorized lists of nonsense syllables and tested himself. He found that forgetting is fast at first and then slows down. Much is lost in the first day. What survives fades slowly after that. This shape is the **forgetting curve**.

Forgetting looks like a flaw but it is a feature. A brain that kept every detail would drown in noise. Imagine remembering every parking spot you ever used. Finding today's would be hard. Forgetting clears out details so general patterns stand out. It also lets us update. When a friend moves, the old address should fade. Some forgetting is active. The brain seems to weaken unused traces on purpose. People who cannot forget often call it a burden.

False memories

Elizabeth Loftus showed how easily memory can be changed. In a 1974 study people watched a film of a car crash. Some were asked how fast the cars were going when they "smashed" into each other. Others heard "hit" or "contacted". The "smashed" group gave higher speed estimates. A week later they were also more than twice as likely to say they saw broken glass. There was no broken glass.

Later work went further. In the "lost in the mall" study, researchers told people a made up story about getting lost in a shopping mall as a child, mixed in with true stories from family members. About a quarter came to recall the false event at least in part. Other studies planted memories of meeting Bugs Bunny at Disneyland. Bugs Bunny is not a Disney character.

This matters for law. Eyewitness errors are a leading factor in wrongful convictions later overturned by DNA evidence. It matters for therapy too. Pushing people to "recover" hidden memories can create false ones. A vivid, confident memory is not proof of accuracy.

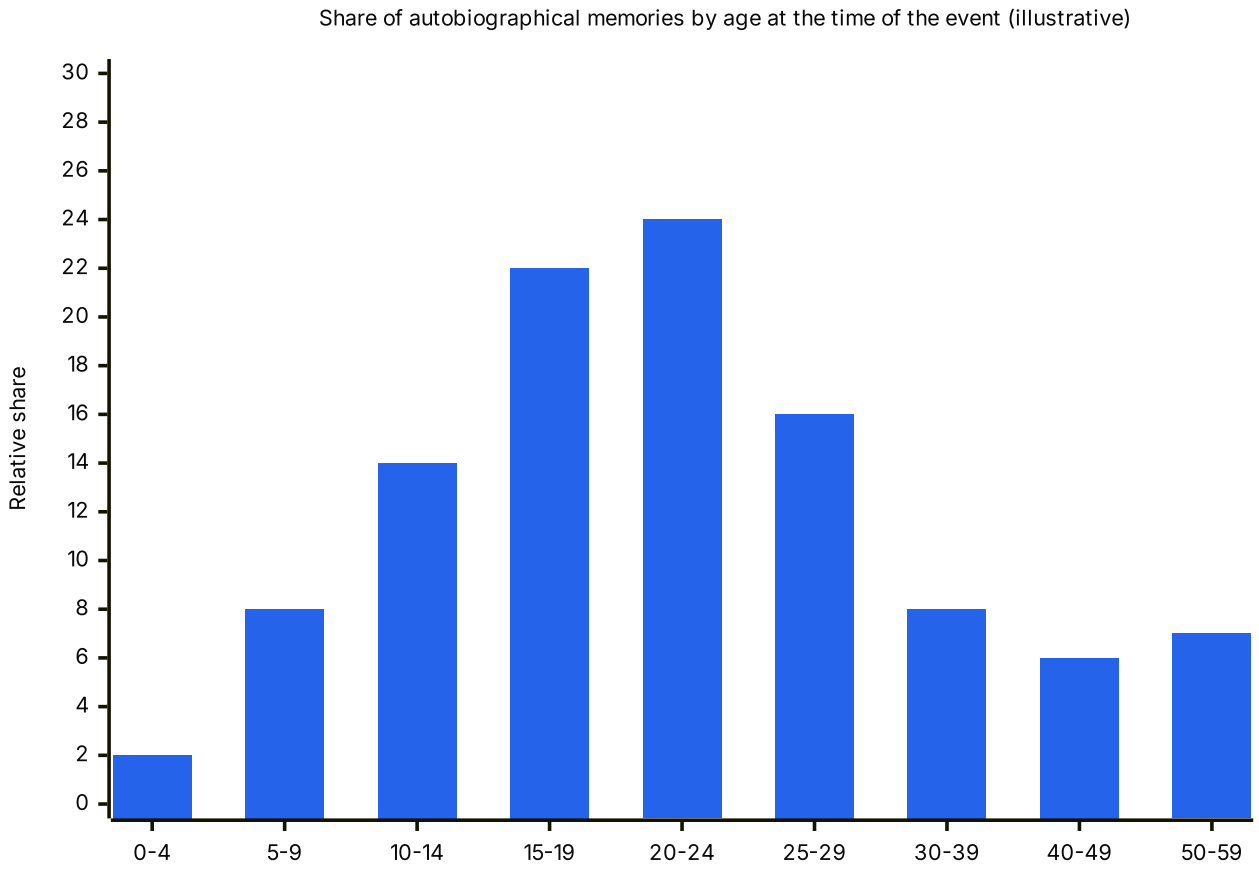
Memory and emotion

Emotional events are remembered better. Stress hormones like adrenaline and cortisol act on the amygdala. The amygdala then boosts storage in the hippocampus and cortex. This is why you remember where you were during a shocking event.

But better is not the same as more accurate. Studies of **flashbulb memories** after events like the September 11 attacks found that details drifted over months just like ordinary memories. Confidence stayed high. Emotion boosts how sure we feel more than how right we are. It also narrows focus. A victim may remember the gun clearly and the attacker's face poorly. This is known as **weapon focus**.

Very strong fear can over strengthen a memory. In **post traumatic stress disorder** it intrudes as if happening again. Some treatments try to use reconsolidation, recalling the memory in a safe setting so it is saved again with less fear. Results so far are mixed.

Memory across the life span



The chart is a simplified sketch of patterns reported for older adults, not exact data. It shows childhood amnesia on the left and the "reminiscence bump" in the late teens and twenties.

Almost no one remembers events from before age two or three. This is **childhood amnesia**. Infants clearly learn. They recognize faces and voices. But those early events do not last as lasting episodic memories. Likely reasons include a still maturing hippocampus, rapid growth of new neurons that may scramble old links, and the lack of language and a sense of self to organize memories. Recent infant brain scan work suggests the hippocampus can encode memories in the first year. The puzzle may be more about retrieval than storage. This remains an active debate.

Older adults recall a burst of memories from their late teens and twenties. This **reminiscence bump** may reflect many firsts, identity forming events and the life stories cultures expect.

With normal aging, working memory and episodic recall decline. Binding details like who told you something gets harder. Semantic memory and vocabulary often hold steady or grow into the seventies. Skills are well kept. Slower processing speed explains part of the decline.

Exceptional memory

Highly superior autobiographical memory (HSAM) was first described in 2006 in a woman named Jill Price. Give people with HSAM a random date from their adult life and they can often say the weekday and what they did. Only a small number of cases have been confirmed. They are not better at memorizing lists or faces. Many revisit their past in an almost obsessive way. Their memories still contain distortions and can absorb false information.

Memory athletes are very different. They are not born with special brains. They use methods like the **memory palace**. You picture a familiar route and place vivid images of the items to learn at each stop. A 2017 study compared top memory athletes with matched controls. Their brain structure looked normal. But the way their brain networks linked up at rest was different. People with no training who practiced the method for six weeks more than doubled their recall of word lists. Their brain connection patterns moved toward those of the athletes. The benefit lasted for months.

When memory breaks

Henry Molaison, known as **H.M.** for most of his life, had both hippocampi and nearby tissue removed in 1953 to stop severe seizures. The seizures improved. But he could no longer form new explicit memories. He met researcher Brenda Milner for decades and never recognized her. Yet he got better at a hard mirror drawing task day by day without remembering doing it. Skill memory clearly relies on different systems from event memory. H.M. died in 2008.

Clive Wearing is a British musician. In 1985 a herpes virus infected his brain and destroyed his hippocampi and more. His memory span is now often described as under a minute. He fills diaries with entries saying he has just woken up for the first time, crossing out the one before. Yet he can still play piano and conduct music. He still greets his wife with deep love each time she appears. Skills and emotional bonds survived where episodic memory did not.

Alzheimer's disease is the most common cause of dementia. More than 55 million people live with dementia worldwide. Alzheimer's accounts for roughly 60 to 70 percent of cases. It

involves clumps of amyloid protein between neurons and tangles of tau protein inside them. Damage usually starts near the hippocampus. That is why recent memory goes first and childhood memories often last longer. Blood tests and brain scans that detect these proteins now allow diagnosis earlier than before.

Memory makes identity

Who are you without your memories? Clive Wearing still seems clearly himself. His tastes, skills and loves persist. People with Alzheimer's keep a sense of self long after recall fades. This suggests identity lives in more than episodic memory. It rests also on values, habits, emotional patterns and the body.

Still, autobiographical memory gives the self its story. We select and retell memories to make sense of our lives. Each retelling is a reconstruction that fits our current goals. The memories we keep say as much about us as the events themselves.

Measurable signals

WHAT	HOW IT COULD BE MEASURED IN A LIVING PERSON
Working memory capacity	Digit span and n back tasks
Episodic and verbal memory	Standard tests such as word list learning with delayed recall
Hippocampal size	Structural MRI
Sleep replay markers	EEG for slow waves and spindles during sleep
Alzheimer's proteins	Blood tests for tau and amyloid. PET scans. Spinal fluid tests
Emotional memory strength	Skin conductance and heart rate during recall
Autobiographical detail	Structured interviews scored for internal versus general detail
Everyday memory in context	Diaries, photo logs and wearable cameras tested against later recall

Key takeaways

- Memory is many systems. Event memory, facts, skills and conditioning can fail apart.
- Memories are encoded, stabilized, moved to the cortex over time and replayed in sleep.
- Recalling a memory can reopen it to change. Memory is reconstruction, not playback.
- Engrams and long term potentiation are the best current answers to where and how memories are stored.
- Forgetting is useful. It removes clutter and supports updating.
- Confidence does not equal accuracy. False memories can be planted with ordinary methods.
- Identity rests on more than recall. Skills, values and emotional bonds survive severe amnesia.

SOURCES AND FURTHER READING

- Scoville, W. B. and Milner, B. (1957). Loss of recent memory after bilateral hippocampal lesions. *Journal of Neurology, Neurosurgery and Psychiatry*. https://doi.org/10.1136/jnnp.20.1.11
- Bliss, T. V. P. and Lømo, T. (1973). Long-lasting potentiation of synaptic transmission in the dentate area of the anaesthetized rabbit. *Journal of Physiology*. https://doi.org/10.1113/jphysiol.1973.sp010273
- Loftus, E. F. and Palmer, J. C. (1974). Reconstruction of automobile destruction. *Journal of Verbal Learning and Verbal Behavior*. https://doi.org/10.1016/S0022-5371(74)80011-3
- Nader, K., Schafe, G. E. and LeDoux, J. E. (2000). Fear memories require protein synthesis in the amygdala for reconsolidation after retrieval. *Nature*. https://doi.org/10.1038/35021052
- Josselyn, S. A. and Tonegawa, S. (2020). Memory engrams: Recalling the past and imagining the future. *Science*. https://doi.org/10.1126/science.aaw4325
- Parker, E. S., Cahill, L. and McGaugh, J. L. (2006). A case of unusual autobiographical remembering. *Neurocase*. https://doi.org/10.1080/13554790500473680
- Dresler, M. et al. (2017). Mnemonic training reshapes brain networks to support superior memory. *Neuron*. https://doi.org/10.1016/j.neuron.2017.02.003
- World Health Organization. Dementia fact sheet. https://www.who.int/news-room/fact-sheets/detail/dementia

CHAPTER 06

Learning and Intelligence

Learning is how experience changes the brain so that behavior changes too. Intelligence is how well a person learns, reasons and solves new problems. This chapter starts with the basic ways all humans learn. It then asks what intelligence is and how it is measured. It covers the strange rise in IQ scores over the last century and what twin studies really say about genes. It looks at the brain basis of intelligence and creativity. It weighs the debate over practice and talent. It covers wisdom and how children's thinking develops. It closes with study methods that work and with emotional and social intelligence.

How learning works

Every form of learning answers one question. What goes with what?

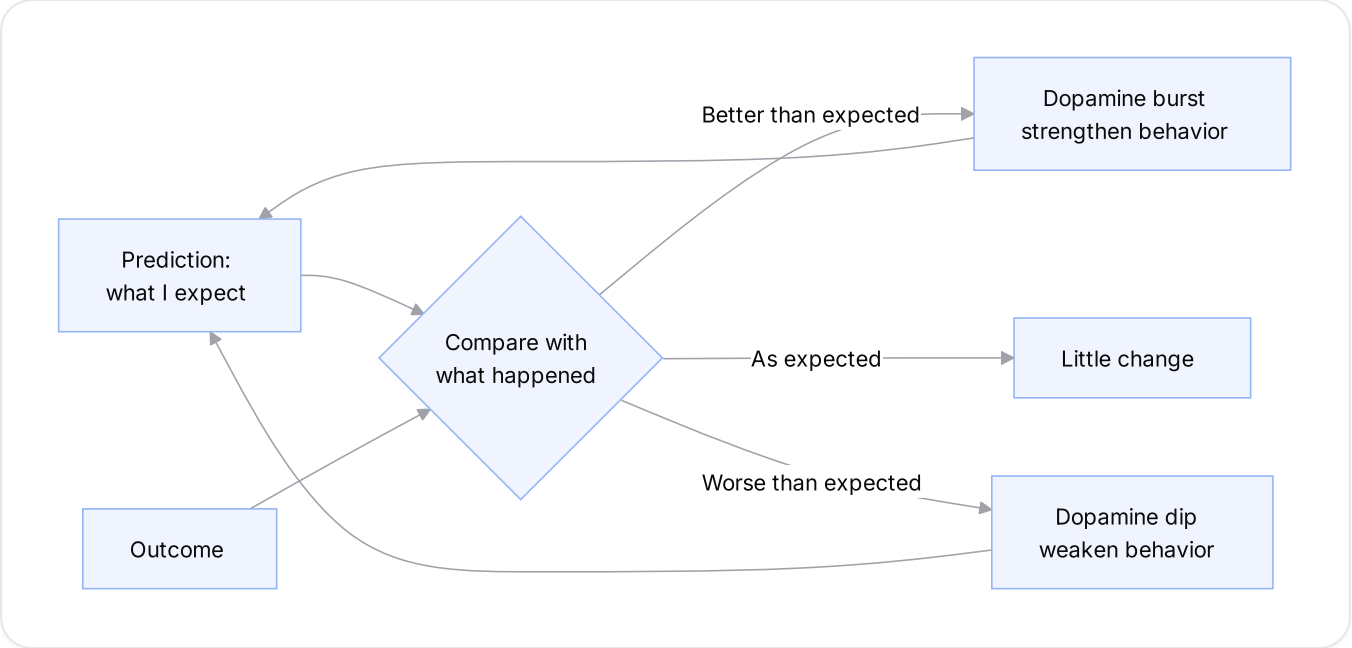
Classical conditioning links two events. Ivan Pavlov rang a bell before feeding dogs. Soon the bell alone made them drool. People learn the same way. The smell of a hospital can bring dread. A ringtone can make your heart jump.

Operant conditioning links actions with results. Rewarded behavior becomes more likely. This is **reinforcement**. Unpredictable rewards build the most stubborn habits, which is why checking a phone is so hard to stop.

Observational learning means learning by watching others. In the 1960s Albert Bandura showed that children who watched an adult hit an inflatable doll copied the exact moves. Humans even copy steps that do not seem needed. This "over imitation" may help culture pass down tools and rituals whose purpose is not obvious.

Statistical learning is quieter. The brain tracks how often things go together without trying. In a 1996 study, eight month old babies heard two minutes of made up syllables with no pauses. Afterwards they could tell "words" (syllables that always went together) from chance pairs. This is likely how babies start finding word edges in speech.

Prediction error ties these together. The brain makes a guess about what will happen. When the result is better or worse than the guess, it learns. When the result matches, it learns little. Dopamine neurons in the midbrain seem to signal exactly this gap. A surprising reward makes them fire hard. An expected one barely changes them. A missing one makes them dip.



What intelligence is

There is no single agreed definition. A common working one is the ability to reason, plan, solve problems, think in the abstract, grasp complex ideas and learn quickly from experience.

In 1904 Charles Spearman noticed something simple. People who do well on one kind of mental test tend to do well on others. Vocabulary, puzzles, memory and math scores all correlate. He called the shared factor **g** for general intelligence. It usually explains around 40 to 50 percent of the differences between people on a broad test battery. The rest comes from more specific abilities and from measurement noise.

Raymond Cattell and John Horn split ability into two kinds. **Fluid intelligence** is solving new problems on the spot, like a pattern puzzle you have never seen. It peaks in early adulthood and then slowly declines. **Crystallized intelligence** is knowledge and skills built up over time, like vocabulary. It keeps growing into late middle age or beyond. Most modern tests follow a layered model with g at the top, broad abilities in the middle and narrow skills at the bottom.

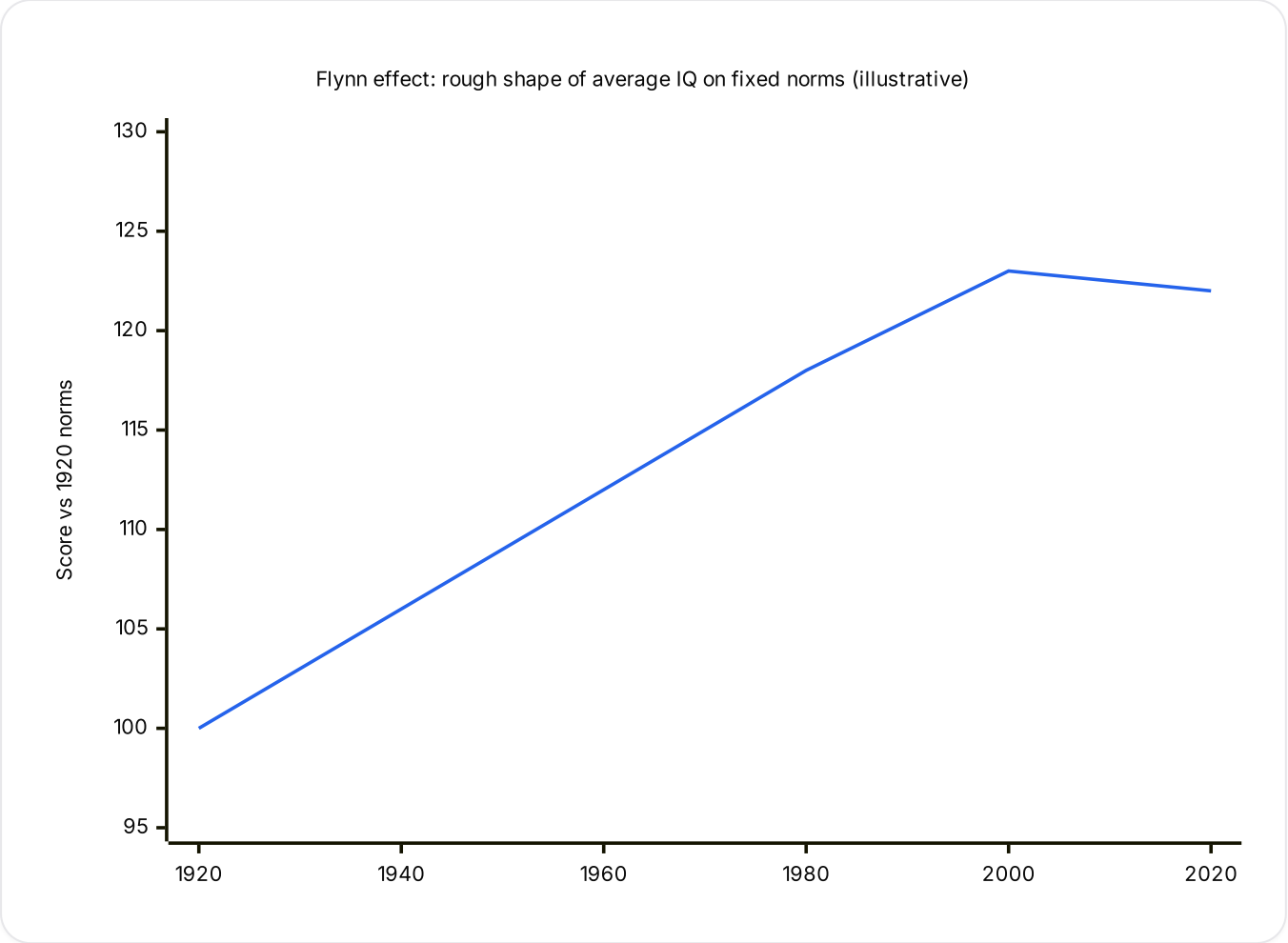
Two popular alternatives push back. Howard Gardner proposed **multiple intelligences**. These include linguistic, logical, spatial, musical, bodily, interpersonal, intrapersonal and naturalist. The idea is popular in schools. But there is little evidence these are separate abilities. Several correlate with each other and with g. Robert Sternberg proposed a **triarchic theory** with analytical, creative and practical intelligence. It rightly stresses real world skill. But tests built from it have had mixed success in showing that the parts are separate from g. Both theories remain debated.

APPROACH	MAIN CLAIM	EVIDENCE STATUS
g factor (Spearman)	One general ability underlies all mental tests	Strong and replicated across many countries
Fluid vs crystallized (Cattell, Horn)	Reasoning on new problems differs from stored knowledge	Strong. Different age curves are well documented
Multiple intelligences (Gardner)	Eight or more separate intelligences	Weak. Little evidence they are independent
Triarchic (Sternberg)	Analytical, creative and practical intelligence	Mixed. Interesting ideas, debated measurement

IQ testing and the Flynn effect

Modern IQ tests set the average at 100. About two thirds of people score between 85 and 115. Scores are fairly stable from late childhood on. They moderately predict school results, job performance and even health and lifespan. They miss much that matters, such as motivation and kindness.

James Flynn noticed that raw IQ scores rose steadily through the 20th century. Across many countries the gain was roughly 2 to 3 points per decade. Gains were largest on fluid reasoning tests. Genes cannot change that fast. Likely causes include better nutrition, less disease, more schooling, smaller families and a world that trains abstract thinking. Since the 1990s some countries such as Norway have seen the trend stall or reverse. Studies comparing brothers show this reversal happens within families. That points to environmental causes rather than changes in who has children. The exact causes of both the rise and the fall are still debated.



The chart shows the general pattern only. Real rates differ by country, test and decade.

Genes and environment

Identical twins share nearly all their genes. Fraternal twins share about half on average. If identical twins are more alike in IQ, genes likely play a role. Twin and adoption studies agree on a clear pattern. The **heritability** of intelligence rises with age. It is around 20 percent in infancy, around 40 percent in childhood and around 50 to 60 percent or more in adulthood. One reason is that people increasingly pick environments that fit their leanings. A child who likes reading seeks more books.

Heritability is widely misunderstood. It is not the share of your own intelligence caused by genes. It describes the share of differences between people in a given population at a given time that track genetic differences. It can change if the environment changes. If everyone got the same schooling, heritability would go up because fewer differences would come from schooling. A trait can be highly heritable and still very responsive to the environment. Height is highly heritable, yet average height rose a lot with better nutrition.

Some US studies found heritability is lower in poor families. The idea is that poverty limits how far genetic potential can show. This pattern has been weaker or absent in some other countries and remains debated.

Gene studies now find thousands of DNA variants linked to intelligence. Each has a tiny effect. Combined into a "polygenic score" they explain a modest share of differences, roughly 10 percent or less for intelligence. Such scores cannot predict any one person's ability well.

The brain basis of intelligence

Bigger brains correlate only weakly with test scores, at about 0.2 to 0.25. Organization matters more than size.

In 2007 Rex Jung and Richard Haier proposed the **parieto frontal integration theory (P-FIT)**. It holds that intelligence depends on a network linking the parietal lobes, which process and combine sensory information, and the frontal lobes, which plan and test solutions. Strong white matter cables between them speed this exchange. Many imaging studies fit this picture, though the network is broad.

A related idea is **neural efficiency**. In some studies higher ability people use less brain activity on easy tasks. On hard tasks this can flip. Other work highlights how readily networks reconfigure between tasks. No single marker explains intelligence. It seems to emerge from how well the whole system is wired and coordinated.

Creativity

Creativity is producing ideas that are both new and useful. A common lab measure is **divergent thinking**. For example, list as many uses for a brick as you can in two minutes. Scores reward the number, variety and rarity of ideas. Creativity correlates with intelligence, especially up to average levels. Above that the link weakens. This "threshold" idea is debated.

Brain studies point to teamwork between two networks that usually work against each other. The **default mode network** is active during mind wandering, memory and imagination. It helps generate ideas. The **executive control network** focuses attention and judges ideas. In a 2018 study, people whose brains linked these two networks (plus a salience network that switches between them) more strongly produced more original ideas. Creative work cycles between loose generation and tight editing. Ideas that arrive in the shower are the default network at work while the critic rests.

Expertise and deliberate practice

How do people become world class? In 1993 Anders Ericsson and colleagues studied violin students at a Berlin academy. The best had piled up the most **deliberate practice** by age 20. This means focused, effortful work on weaknesses with feedback, not just playing for fun. Journalist Malcolm Gladwell later popularized this as a "10,000 hour rule". Ericsson said that rule distorted his work.

The debate grew. A 2014 meta analysis by Brooke Macnamara and colleagues found that practice explained about 26 percent of performance differences in games, 21 percent in music and 18 percent in sports. In education it explained 4 percent. In professions it explained less than 1 percent. Practice clearly matters. But much of the gap between people comes from other factors. These include starting age, working memory, personality, genes and the quality of coaching. Ericsson's supporters argue those studies used too broad a definition of practice. The fair view is that practice is needed for expertise but is not the whole story.

Experts differ from novices mainly in how they see. A chess master sees meaningful patterns, not 25 separate pieces. Expertise is largely well organized knowledge built through years of feedback.

Wisdom

Wisdom is not the same as intelligence. Researchers describe it as good judgment about hard life problems. Key parts include intellectual humility, seeing several points of view, knowing that situations change and seeking compromise. The Berlin Wisdom Paradigm scored people's advice on tricky life dilemmas. Later work by Igor Grossmann found people reason more wisely about other people's problems than their own. Imagining your problem from a third person view can narrow that gap. Wisdom can grow with experience but not simply with age.

How children's thinking develops

Jean Piaget proposed that children pass through four stages.

STAGE (PIAGET)	TYPICAL AGE	HALLMARK	MODERN UPDATE
Sensorimotor	0 to 2	Learning through action and senses. Object permanence	Infants show some object knowledge much earlier in looking studies. Some findings are debated
Preoperational	2 to 7	Symbols and pretend play. Egocentric thinking	Children pass false belief tests around age 4. Signs of perspective taking appear earlier
Concrete operational	7 to 11	Logic about real objects. Conservation	Skills appear unevenly across tasks rather than all at once
Formal operational	11 and up	Abstract and hypothetical reasoning	Many adults use it only in familiar areas

Piaget was right that children actively build their understanding. But development is more gradual and uneven than strict stages suggest. Babies stare longer at "impossible" events, hinting at early grasp of objects and numbers. How much real understanding this shows is debated.

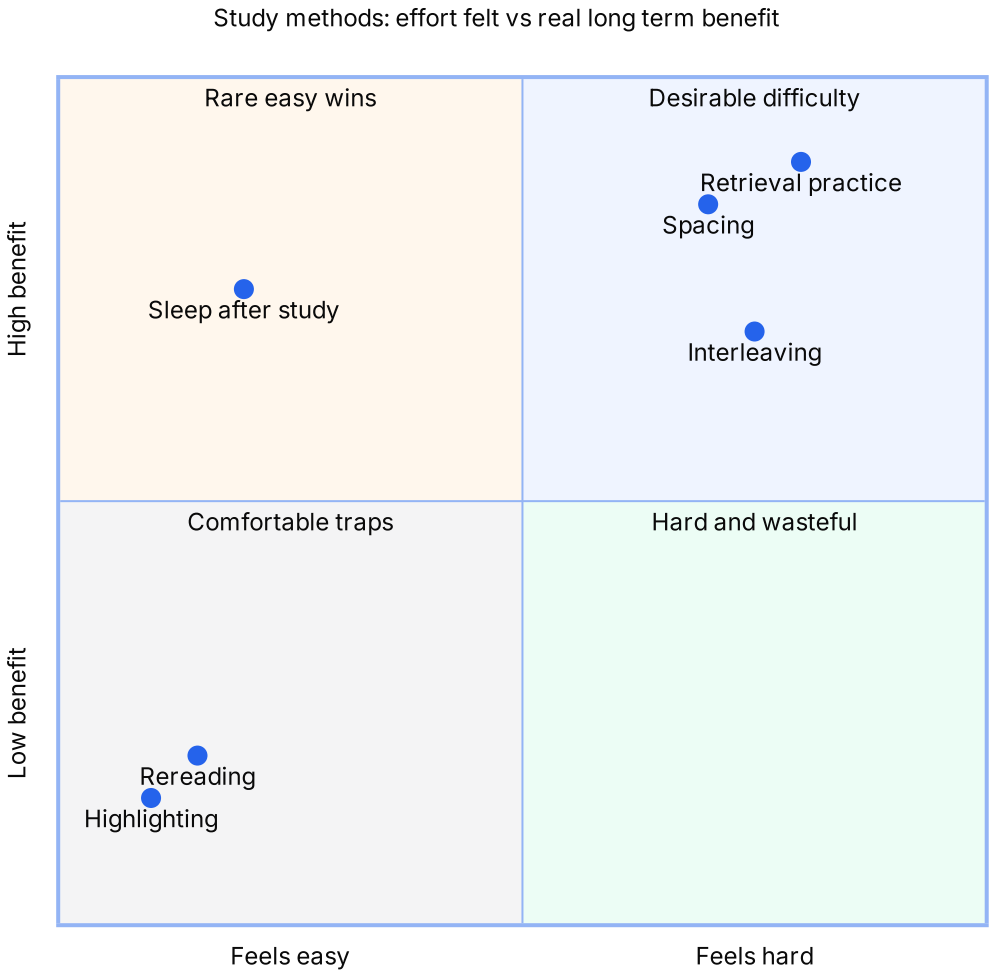
Lev Vygotsky added the social side. He stressed that children learn through talk and shared activity with more skilled people. His **zone of proximal development** is the gap between what a child can do alone and what they can do with help. Good teaching works in that zone. It offers support, or **scaffolding**, then removes it step by step. Language starts as talk with others, becomes private speech aloud and finally inner speech that guides thinking.

Learning methods that work

A large 2013 review rated common study techniques. Some popular ones did poorly. Others were clear winners.

- **Retrieval practice.** Testing yourself beats rereading. In one study self testers remembered far more a week later, though restudying felt more effective.
- **Spacing.** Spreading study over days beats cramming. The best gap grows with how long you need to remember.
- **Interleaving.** Mixing types of problems helps you learn when to use each method.

- **Sleep.** Sleep after learning protects and strengthens new memories, as Chapter 5 explained.
- **Low value methods.** Highlighting and rereading feel productive but add little. The popular idea of matching teaching to "learning styles" like visual or auditory has not held up in controlled tests.



Emotional and social intelligence

Emotional intelligence was defined by Peter Salovey and John Mayer as the ability to perceive, use, understand and manage emotions. Daniel Goleman's 1995 book made it famous with claims that it matters more than IQ. Those claims went beyond the data. When measured as an ability with right and wrong answers, emotional intelligence predicts some job and social outcomes beyond IQ and personality, though modestly. Self report versions overlap heavily with personality traits. So the concept is real but its size is debated.

Social intelligence covers reading others and handling relationships. It relies on **theory of mind**, the ability to model what others think and believe. The brain network for this includes the temporoparietal junction and medial prefrontal cortex. Some studies found that teams with equal turn taking and better emotion reading solve problems better. Replications have been mixed.

Measurable signals

WHAT	HOW IT COULD BE MEASURED IN A LIVING PERSON
General and fluid intelligence	Standard IQ batteries such as the WAIS. Matrix reasoning tests
Crystallized knowledge	Vocabulary and general knowledge tests
Learning rate and prediction error	Reward learning games. Pupil size. fMRI of the striatum in lab settings
Brain network efficiency	Resting state fMRI. Diffusion MRI of white matter
Divergent thinking	Alternate uses tasks scored for fluency and originality
Expertise	Domain tests and practice logs
Emotional intelligence	Ability tests such as the MSCEIT. Emotion recognition from faces
Study habits	Learning app logs of spacing and self testing

Key takeaways

- Most learning boils down to linking events and updating when predictions are wrong. Dopamine signals that error.
- A general factor g is real and well supported. Fluid and crystallized abilities age differently.
- IQ rose about 2 to 3 points per decade in the 20th century. Some countries now show a reversal. Both point to environment.
- Heritability rises with age and describes groups, not individuals. High heritability does not mean fixed.
- Intelligence depends on how well brain networks, especially parietal and frontal ones, connect and coordinate.
- Practice is necessary but explains only part of expertise.
- Self testing, spacing and sleep are the best supported ways to learn.

SOURCES AND FURTHER READING

- Schultz, W., Dayan, P. and Montague, P. R. (1997). A neural substrate of prediction and reward. *Science*. https://doi.org/10.1126/science.275.5306.1593
- Saffran, J. R., Aslin, R. N. and Newport, E. L. (1996). Statistical learning by 8-month-old infants. *Science*. https://doi.org/10.1126/science.274.5294.1926
- Plomin, R. and Deary, I. J. (2015). Genetics and intelligence differences: five special findings. *Molecular Psychiatry*. https://doi.org/10.1038/mp.2014.105
- Jung, R. E. and Haier, R. J. (2007). The Parieto-Frontal Integration Theory (P-FIT) of intelligence. *Behavioral and Brain Sciences*. https://doi.org/10.1017/S0140525X07001185
- Bratsberg, B. and Rogeberg, O. (2018). Flynn effect and its reversal are both environmentally caused. *PNAS*. https://doi.org/10.1073/pnas.1718793115
- Macnamara, B. N., Hambrick, D. Z. and Oswald, F. L. (2014). Deliberate practice and performance in music, games, sports, education, and professions. *Psychological Science*. https://doi.org/10.1177/0956797614535810
- Beaty, R. E. et al. (2018). Robust prediction of individual creative ability from brain functional connectivity. *PNAS*. https://doi.org/10.1073/pnas.1713532115
- Dunlosky, J. et al. (2013). Improving students' learning with effective learning techniques. *Psychological Science in the Public Interest*. https://doi.org/10.1177/1529100612453266

CHAPTER 07

Emotions and the Body

An emotion is not a thing that lives in one spot in the brain. It is a whole body event. The heart speeds up. The skin sweats. The face moves. The brain then makes sense of all this in light of what is going on around you. Scientists still argue about how much of an emotion is built in and how much the brain builds on the spot. This chapter lays out the main theories and where the debate stands. It then walks through the body signals and brain areas involved. It ends with how emotions grow in childhood, how people steer them and how feelings shift across a day and a life.

Four words that people mix up

Everyday speech uses "emotion", "feeling", "mood" and "affect" as if they meant the same thing. Scientists keep them apart.

TERM	PLAIN MEANING	HOW LONG IT LASTS	EXAMPLE
Affect	The basic sense of feeling good or bad and calm or worked up	Always present	A vague unease on a gray morning
Emotion	A short reaction to a specific event. It involves body, face, thoughts and urges to act	Seconds to minutes	Anger when someone cuts in line
Feeling	The conscious experience of an emotion. What it is like from the inside	As long as you notice it	"I feel furious"
Mood	A low level state with no clear cause or target	Hours to days	Being grumpy all afternoon

Affect is the floor everything else stands on. An emotion has a target. A mood does not. A feeling is the part you notice. You can have an emotion with little feeling. People often show stress in their body before they can name it.

The big theories

For more than a century researchers have argued about one question. Which comes first, the body change or the feeling?

James and Lange (1880s). William James and Carl Lange said the body comes first. You see a bear. Your heart pounds and you run. The feeling of fear is your sense of those body changes. James put it simply: we feel afraid because we tremble.

Cannon and Bard (1920s). Walter Cannon pushed back. Body changes are slow and look alike across very different emotions. A racing heart comes with fear, anger and joy. So he argued that the brain triggers the feeling and the body response at the same time.

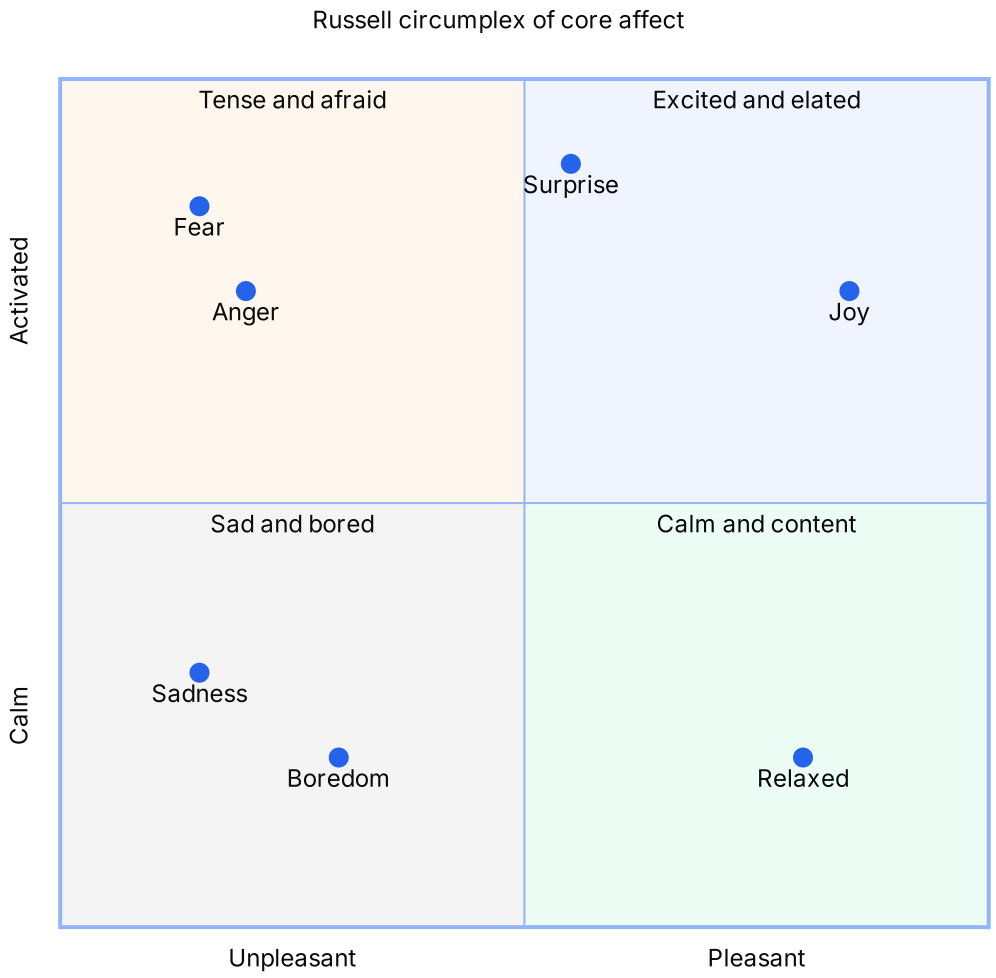
Schachter and Singer two factor theory (1962). Stanley Schachter and Jerome Singer said you need two things. One is general body arousal. The other is a label you pick from the situation. In their study people got an adrenaline shot. Those not told what the shot would do were more likely to take on the mood of a fellow participant who acted happy or angry. The study has been hard to repeat cleanly. The core idea still matters. The same racing heart can be read as fear or thrill depending on context.

Basic emotions (Paul Ekman). Ekman argued for a small set of built in emotions. These are happiness, sadness, fear, anger, surprise and disgust. Each is said to have its own face and body pattern. He showed people in many countries, including a remote group in Papua New Guinea, could match faces to stories well above chance.

Appraisal theory (Richard Lazarus, Klaus Scherer). Emotions come from how you judge a situation. Is this relevant to me? Is it good or bad for my goals? Who caused it? Can I cope? The same event leads to different emotions in different people because they judge it differently. A missed train makes one person angry and another relieved.

Core affect and the circumplex (James Russell, 1980). Russell placed all feelings on two axes. One runs from pleasant to unpleasant. This is called valence. The other runs from calm to activated. This is called arousal. Excitement is pleasant and high arousal. Contentment is pleasant and low. Panic is unpleasant and high. Boredom is unpleasant and low.

Constructed emotion (Lisa Feldman Barrett). Barrett argues that the brain is always predicting what the body needs next. It uses core affect plus learned concepts to build an emotion on the spot. On this view "anger" is not one fixed program. It is a category, like "game", whose members look quite different.



Where the debate stands. Most researchers now agree on a few points. Body arousal matters but does not fix which emotion you feel. Context and judgment shape the result. Faces carry some emotional signal but far less than the classic view claimed. A large 2019 review led by Barrett found that people scowl when angry only about 20 to 30 percent of the time. They also scowl when they are just concentrating. The live split is between basic emotion theorists, who see a few core programs refined by culture, and constructionists, who see no fixed programs at all. Appraisal theory sits in the middle and is widely used.

The body side of emotion

The autonomic nervous system. This is the part of the nervous system that runs without your control. It has two main branches. The sympathetic branch gears you up. It raises heart rate, widens pupils and moves blood to muscles. The parasympathetic branch calms you down. It slows the heart and helps digestion. Both are active all the time like a gas pedal and a brake.

Heart rate and heart rate variability. Your heart does not beat like a metronome. The gap between beats changes slightly from beat to beat. This change is called heart rate variability or HRV. Higher resting HRV usually means the calming branch has good control. Lower HRV is linked with stress, poor sleep and some mood problems. HRV differs a lot between people and with age. So it is most useful when you compare a person to their own baseline.

Skin conductance. Sweat glands on the palms and fingers are driven only by the sympathetic branch. When you get aroused they release a tiny amount of sweat. This makes the skin conduct electricity better. It tracks arousal well but not valence. A surprise party and a near car crash look similar on this signal.

Breathing. Fear and anger bring fast shallow breathing. Sadness brings sighs. Slow breathing at around six breaths a minute tends to raise HRV and calm people. That is one reason breathing exercises work for many.

Face and voice. About 40 muscles move the face. Two are studied most. The corrugator muscle pulls the brows together during negative feelings. The zygomaticus muscle pulls the lip corners up in smiles. Electrodes can pick up tiny activity in them even when no expression is visible. The voice also shifts. Arousal raises pitch, loudness and speed. Sadness lowers pitch and slows speech.

Hormones and brain chemicals.

CHEMICAL	MAIN JOB IN EMOTION	COMMON MYTH TO AVOID
Adrenaline	Fast surge for action. Raises heart rate and blood sugar within seconds	That it only means fear. It rises with excitement too
Cortisol	Slower stress hormone. Mobilizes energy over minutes to hours. Also follows a daily rhythm	That it is simply "bad". It is needed to wake up and cope
Oxytocin	Bonding, trust and caregiving, also childbirth and nursing	That it is a "love hormone". It can also increase favoring your own group. Many nasal spray studies did not replicate
Dopamine	Wanting, motivation and learning from surprise rewards (see Chapter 8)	That it is the "pleasure chemical"
Serotonin	Broad role in mood, impulse control and patience	That depression is simply "low serotonin". A 2022 umbrella review found weak support for that idea

The vagus nerve and polyvagal theory. The vagus nerve is a long nerve from the brainstem to the heart, lungs and gut. It carries much of the calming signal to the heart. About 80 percent of its fibers carry signals up from the body to the brain. Stephen Porges proposed polyvagal theory in 1995. It claims there are three ranked body states tied to safety, danger and life threat. It is popular in therapy circles. **It is heavily debated.** Critics such as Paul Grossman argue that several of its core claims about evolution and anatomy are wrong. Treat it as a metaphor, not settled science.

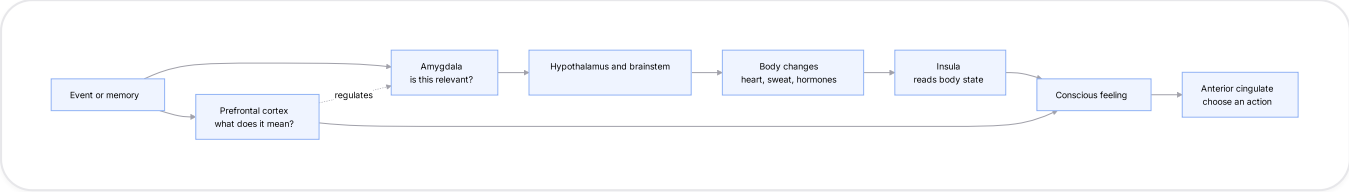
Interoception. This is your sense of the inside of your body. It includes heartbeat, breathing, hunger, gut feelings and temperature. People differ in how well they sense these. One common test asks people to count their heartbeats without touching their pulse. Many are poor at it. Barrett and others see interoception as a core ingredient of feelings.

The brain side of emotion

In 1952 Paul MacLean grouped several deep brain areas into a "limbic system". He called it the seat of emotion. The idea stuck in textbooks. It is now seen as outdated for three reasons. There is no agreed list of which areas belong to it. Some of its parts, like the hippocampus,

mainly serve memory. And emotion uses large networks that reach across the cortex. A 2012 meta analysis by Kristen Lindquist and colleagues pooled about 90 brain imaging studies. It found no single region that is specific to any one emotion.

REGION	WHAT IT DOES IN EMOTION
Amygdala	Flags things that are relevant or uncertain, especially threats. A patient called S.M. with damage to both amygdalae showed almost no fear of snakes or spiders
Insula	Maps the state of the body. Central for interoception, disgust and the felt side of emotion
Anterior cingulate cortex	Notices conflict and pain. Links feelings with choosing what to do
Prefrontal cortex	The front of the brain. Holds goals, reappraises events and dampens or boosts responses
Hypothalamus and brainstem	Drive the hormone and autonomic outputs

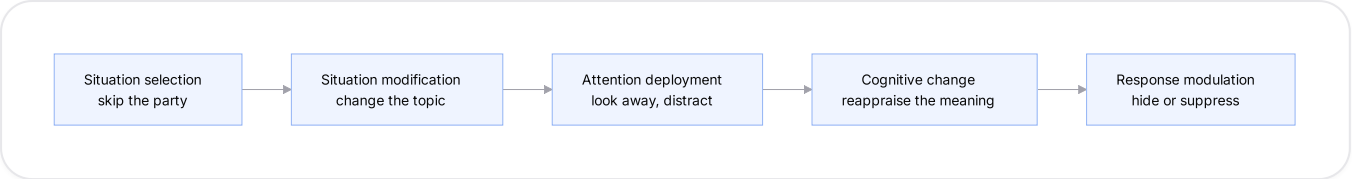


How emotions develop

Newborns show distress, contentment and interest. A social smile appears at about six to eight weeks. Anger and fear become clear by around six to eight months. Wariness of strangers often peaks near eight to ten months. Around the first birthday babies start social referencing. They look at a parent's face to decide whether something new is safe. Self conscious emotions like shame, pride, guilt and embarrassment need a sense of self. They appear around 18 to 24 months and grow through the preschool years. Children learn emotion words from parents. Parents who talk about feelings tend to raise children who understand feelings sooner.

Emotion regulation

James Gross's process model sorts the ways people steer emotions by when they act.



Early strategies tend to work better. Reappraisal means reframing what an event means. "The interviewer is tough on everyone, not just me." It usually lowers bad feelings without much cost. Suppression means hiding the outward signs. It often leaves the inner feeling and the body arousal intact. In lab studies it also hurt memory for the conversation. No strategy is good in every case. Flexibility in picking the right one for the moment matters most.

Emotional granularity is how finely a person tells feelings apart. One person says "I feel bad". Another can tell irritated from disappointed from lonely. Higher granularity is linked with better coping and less binge drinking under stress. It can be trained by learning more emotion words.

Hedonic adaptation is the way people drift back toward their usual level of happiness after good or bad events. A pay rise feels great for a few months. Then it becomes normal. A famous 1978 study compared lottery winners with people who had become paralyzed. It found smaller long term differences than expected. Later work shows adaptation is not complete. Losing a job or a partner can lower life satisfaction for years.

Mood disorders are what happens when mood stops tracking life events. In major depression low mood or loss of pleasure lasts at least two weeks and harms daily life. The World Health Organization estimates that about 5 percent of adults have depression at any time. Bipolar disorder adds periods of abnormally high energy and mood. Anxiety disorders involve fear that is out of scale with the threat.

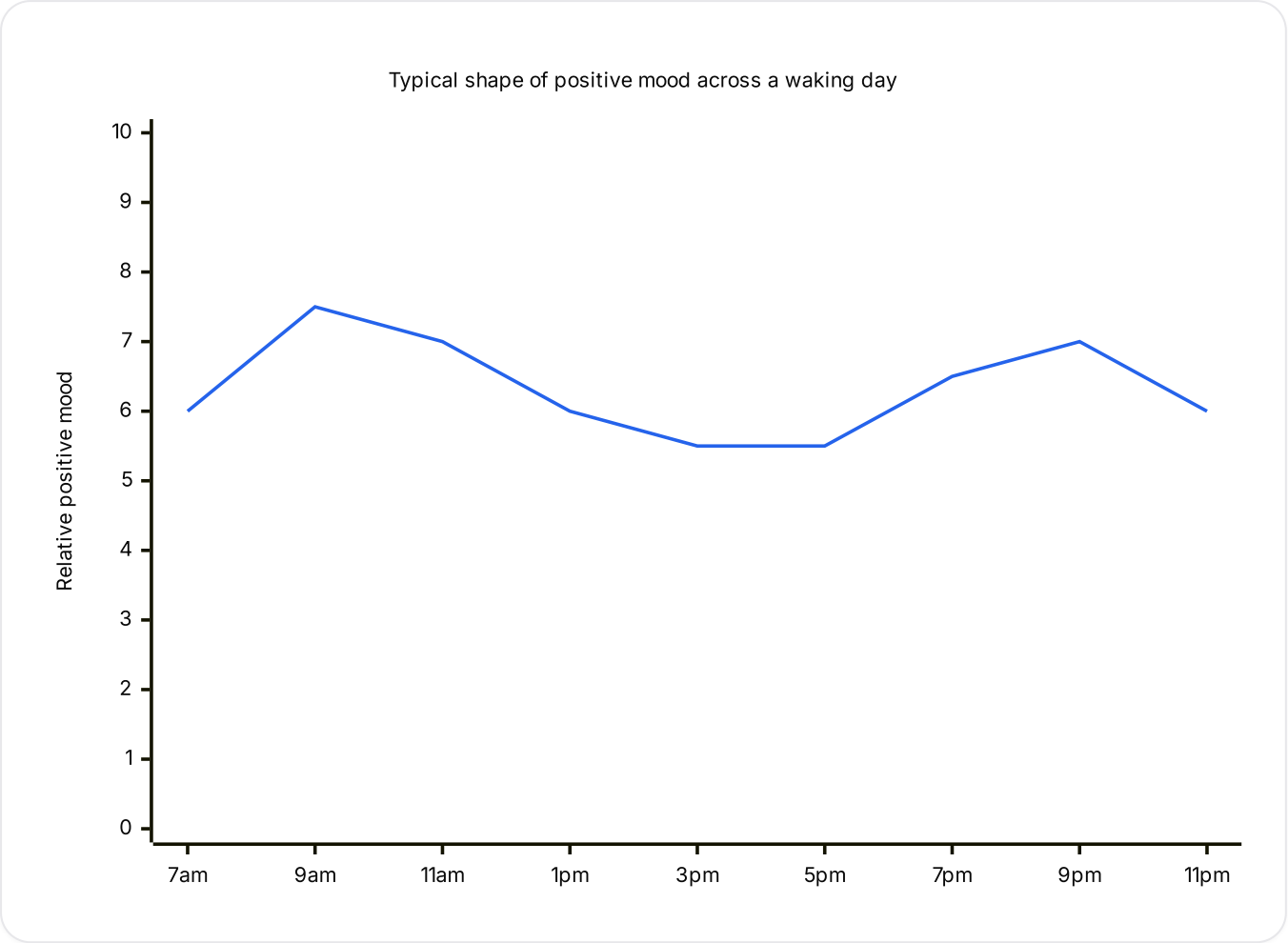
Culture and emotion

Cultures differ in which emotions they value and how openly they show them. In many East Asian settings calm, low arousal states are prized. In the United States excited, high arousal states are prized more. Display rules say when to show or hide a feeling. Some languages carve feelings differently. German "Schadenfreude" names pleasure at another's bad luck. Japanese "amae" names a pleasant dependence on someone's goodwill. Recognition of

facial expressions across cultures is above chance. But it is lower when people must name the emotion freely rather than pick from a short list.

Feelings across a day and a life

Feelings follow a daily rhythm. Cortisol rises sharply in the 30 to 45 minutes after waking and then falls through the day. A 2011 study of over 500 million tweets found positive mood peaked in the morning and rose again in the evening, with weekends brighter. Sleep loss makes the amygdala react more strongly to bad images and makes people more irritable.



The chart is a simplified shape based on the pattern in Golder and Macy 2011. Individuals vary a lot.

Across the life span, teenagers show more intense and faster changing emotions. Older adults often report fewer negative feelings and pay more attention to positive information. This is called the positivity effect. Laura Carstensen explains it with socioemotional selectivity theory. When time feels limited people focus on what feels meaningful now. Some

large surveys find a U shaped curve in life satisfaction with a low point around the late 40s. **This U shape is debated.** It depends on which controls the analysts use.

Measurable signals

SIGNAL	WHAT IT TELLS YOU	HOW IT IS MEASURED ON A LIVING PERSON
Heart rate and HRV	Arousal and calming capacity	Chest strap ECG, finger or wrist optical sensor
Skin conductance	Moment to moment arousal	Electrodes on fingers or palm, wrist sensor
Breathing rate and depth	Arousal, sighing, calm	Chest belt, wearable, microphone
Facial muscle activity	Smiling, frowning, valence	Facial EMG electrodes, video camera coding
Voice	Arousal and some valence	Microphone analysis of pitch, loudness and rate
Cortisol	Stress over minutes to hours	Saliva samples, hair samples for months
Self report	The felt side, granularity	Phone prompts several times a day called experience sampling

Key takeaways

- Affect is the basic good or bad and calm or activated tone. Emotions are short reactions. Moods last longer and lack a target.
- Body arousal is real but does not decide by itself which emotion you feel. Context and judgment shape the result.
- There is no single "fear center" and the limbic system idea is outdated. Emotion uses networks across the brain.
- Faces and body signals carry emotional information but are not a reliable readout on their own.
- Polyvagal theory is popular but heavily debated.
- Reappraisal usually works better than suppression. Flexibility matters most.
- Feelings follow daily and life span rhythms. Older adults tend to be emotionally steadier.

SOURCES AND FURTHER READING

- Gross, J. J. (1998). The emerging field of emotion regulation: An integrative review. *Review of General Psychology*. https://doi.org/10.1037/1089-2680.2.3.271
- Russell, J. A. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology*. https://doi.org/10.1037/h0077714
- Barrett, L. F. (2017). The theory of constructed emotion. *Social Cognitive and Affective Neuroscience*. https://doi.org/10.1093/scan/nsw154
- Ekman, P. (1992). An argument for basic emotions. *Cognition and Emotion*. https://doi.org/10.1080/02699939208411068
- Barrett, L. F., et al. (2019). Emotional expressions reconsidered. *Psychological Science in the Public Interest*. https://doi.org/10.1177/1529100619832930
- Lindquist, K. A., et al. (2012). The brain basis of emotion: A meta-analytic review. *Behavioral and Brain Sciences*. https://doi.org/10.1017/S0140525X11000446
- Craig, A. D. (2002). How do you feel? Interoception. *Nature Reviews Neuroscience*. https://doi.org/10.1038/nrn894
- Grossman, P. (2023). Fundamental challenges and likely refutations of the five basic premises of the polyvagal theory. *Biological Psychology*. https://doi.org/10.1016/j.biopsycho.2023.108589

CHAPTER 08

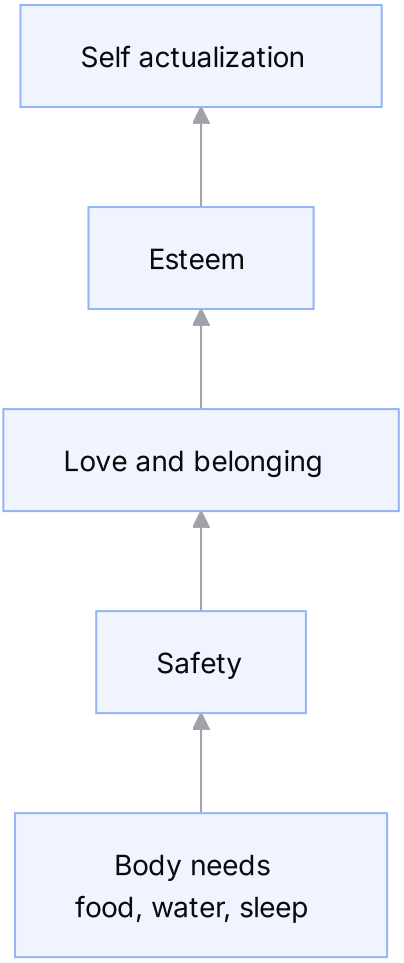
Motivation and Decision Making

Motivation is what gets you moving. Decision making is how you pick a direction. Both rest on a body that needs food, warmth and sleep and on a brain that learns from surprise. People are not the cool calculators of old economics textbooks. Nor are they hopeless bundles of bias. They use fast rules of thumb that work well most of the time and fail in predictable ways. This chapter covers drives and needs, the reward system, habits, self control, the two speeds of thinking, risk and time, the role of emotion, moral and group choices, expert intuition, how body states bend choices and the sting of regret.

Drives and needs

The oldest layer of motivation is **homeostasis**. That is the body's effort to keep things like temperature, blood sugar and water within a safe range. When a value drifts, a drive pushes you to fix it. Thirst, hunger, cold and tiredness are drives. The hypothalamus, a small area at the base of the brain, senses many of these values and starts the fix. Hormones help. Ghrelin from the stomach rises before meals and increases hunger. Leptin from fat tissue signals long term energy stores.

Maslow's hierarchy (1943). Abraham Maslow proposed that needs come in layers. Body needs come first, then safety, then love and belonging, then esteem, then self actualization. The pyramid picture was added later by others. It is easy to remember but the strict order does not hold up well. People in hard conditions still seek love and meaning. Starving artists exist. A 2011 study using global survey data found that basic needs and social needs both predicted well being largely independently of each other.

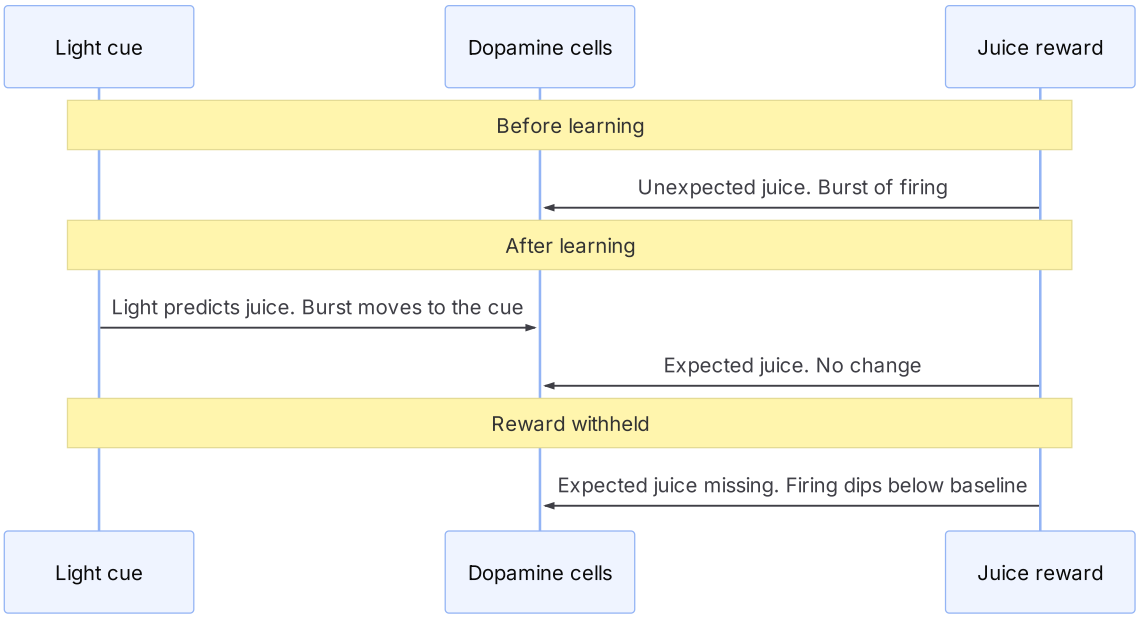


Maslow's original idea as usually drawn. In real life the layers overlap and do not need to be met in order.

Self determination theory (Edward Deci and Richard Ryan). This is the best supported modern framework. It says people have three core psychological needs. **Autonomy** is feeling that your actions are your own choice. **Competence** is feeling effective. **Relatedness** is feeling connected to others. When these are met, people show more **intrinsic motivation**. That means doing something because it is interesting in itself. Rewards can sometimes undercut this. A child paid to draw may draw less once the payments stop. Whether this happens depends on whether the reward feels controlling or informative.

The reward system and dopamine

Dopamine cells sit deep in the midbrain. They send signals to the striatum and the prefrontal cortex. In the 1990s Wolfram Schultz recorded these cells in monkeys. His results, modeled with Peter Dayan and Read Montague in 1997, changed the field. The cells did not simply fire to rewards. They fired to **surprise** about rewards.



This is called a **reward prediction error**. It is the gap between what you expected and what you got. Better than expected gives a burst. Worse gives a dip. As expected gives nothing. This explains everyday life. The first bite of a great dessert thrills. The tenth bite of the same dessert does not. A bonus you counted on feels like nothing. A missing bonus feels like a loss.

Wanting versus liking (Kent Berridge). Dopamine is often called the pleasure chemical. Berridge showed that is wrong. Rats with almost no dopamine still made pleased faces when given sugar. They just would not work to get it. So dopamine drives **wanting**, the pull toward something. **Liking**, the pleasure itself, depends on small "hedonic hotspots" using opioid and related chemicals. The two usually go together but can split. In addiction, wanting can grow while liking stays the same or falls. A person can crave something they no longer enjoy.

Habits versus goals

Some actions are goal directed. You do them because you want the result and you would stop if the result lost value. Others are habits. A cue triggers them automatically. Studies by Wendy Wood suggest that around 40 percent of daily actions are done in the same place almost every day and often while thinking about something else. Habits shift control from the front of the striatum to the back part, called the dorsolateral striatum. A 2010 study by Phillippa Lally and colleagues tracked people forming new habits like drinking water after breakfast. Reaching near automatic behavior took a median of 66 days. The range was 18 to 254 days. The popular "21 days" figure has no solid basis.

Willpower and self control

Self control means overriding an urge for a longer term goal. Walter Mischel's marshmallow test from the 1960s and 1970s asked young children to wait for a second treat. Early follow ups linked waiting to later success. A larger 2018 replication found the link was much weaker once family background was taken into account.

Ego depletion was the idea that willpower is like a muscle that runs out. Resisting cookies would leave you less able to persist on a puzzle. Hundreds of studies seemed to support it. Then in 2016 a preregistered replication across 23 labs with over 2,000 people found an effect close to zero. A second large project in 2021 found at most a tiny effect. **Ego depletion as originally described is now widely doubted.** What does seem to work is avoiding temptation in the first place. People who appear to have great self control often just set up their lives so they face fewer temptations.

Two speeds of thinking

Daniel Kahneman popularized the terms **System 1** and **System 2**. System 1 is fast, automatic and effortless. It reads a face or completes "bread and ...". System 2 is slow, effortful and deliberate. It does long division or checks an argument. The labels are useful shorthand. But there are caveats. They are not two brain parts. Many researchers prefer "Type 1 and Type 2 processes". Fast thinking is often right. Slow thinking can also go wrong, for example when people use reasoning to defend what they already believe.

Heuristics and biases

A heuristic is a mental shortcut. In 1974 Amos Tversky and Kahneman described three key ones.

HEURISTIC	WHAT IT DOES	EXAMPLE OF A FAILURE
Availability	Judges how common something is by how easily examples come to mind	Fearing plane crashes more than car crashes after news coverage
Representativeness	Judges by how much something fits a stereotype	Thinking a quiet bookish person is more likely a librarian than a salesperson, ignoring that salespeople far outnumber librarians
Anchoring	Starts from a number and adjusts too little	A high first price in a negotiation pulls the final deal up

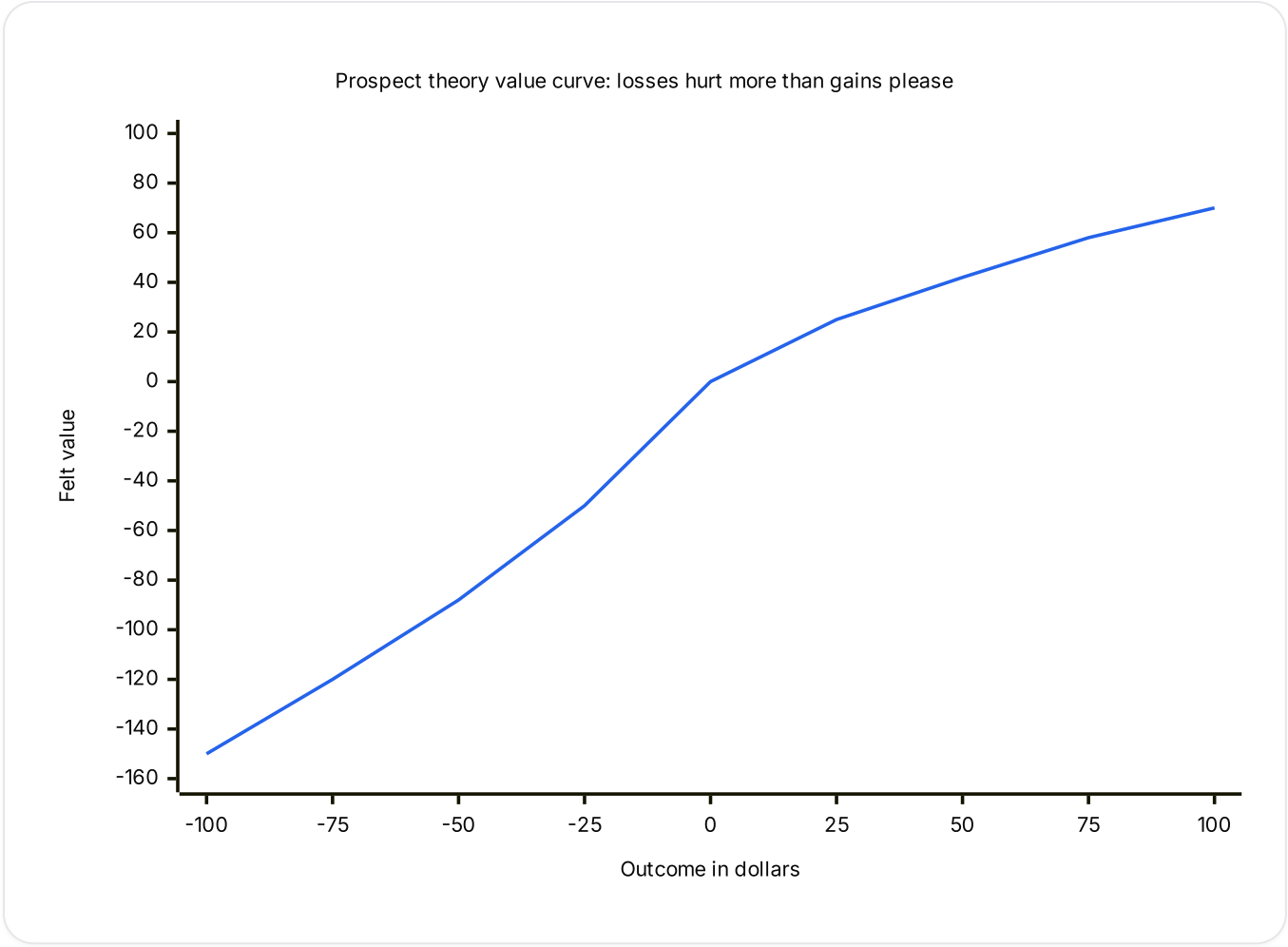
Other well known biases include confirmation bias, seeking facts that support what you believe, and overconfidence. Gerd Gigerenzer argues that simple heuristics are often smart in the real world. They match the structure of the environment. Both camps agree that the shortcuts are useful. They disagree on how often they mislead.

Prospect theory, loss aversion and risk

In 1979 Kahneman and Tversky published **prospect theory**. It says people judge outcomes as gains or losses from a reference point, not as total wealth. It also says the pain of a loss is larger than the joy of an equal gain. Many people refuse a coin flip where they win 110 dollars or lose 100 dollars. Early estimates put losses at about twice the weight of gains. People also overweight small chances. This helps explain why people buy lottery tickets and insurance at the same time.

Loss aversion is debated. David Gal and Derek Rucker argued in 2018 that the evidence is weaker than its fame suggests. With small stakes many people show little or no loss aversion. Several later meta analyses still find it on average, with ratios often between about 1.3 and 2.5. The fair summary is that loss aversion is real for many people in many settings but is not a fixed law.

Economists separate **risk** from **uncertainty**. Under risk you know the odds, as with a fair die. Under uncertainty, also called ambiguity, you do not. People usually dislike ambiguity even more than risk. They prefer betting on an urn with 50 red and 50 black balls over an urn with an unknown mix.



Time discounting

People value rewards less the further away they are. This is called discounting. It is not simply rational. Many people take 100 dollars today over 110 dollars tomorrow. But they choose 110 dollars in 366 days over 100 dollars in 365 days. The same one day wait matters a lot when it is now and little when it is far off. This pattern is called **hyperbolic** or present biased discounting. It helps explain putting off saving, exercise and dental visits.

Emotion in choice

Antonio Damasio studied patients with damage to the ventromedial prefrontal cortex. This is a region just above the eyes. They scored normally on IQ tests yet made terrible life choices. Damasio proposed the **somatic marker hypothesis**. It says body signals tied to past outcomes, like a twinge of unease, steer choices before we can explain them. In the Iowa Gambling Task players draw from four decks. Two give big wins but bigger losses. In a 1997 study healthy players showed rising skin conductance before picking from the bad decks. This happened before they could say which decks were bad. Patients with the damage did not show this. **The theory is debated.** Later studies found that players often do have some

conscious knowledge of the decks early on. Even so, the wider point that emotion is part of good choice, not just a source of error, is broadly accepted.

Moral and social decisions

Trolley problems ask if you would divert a runaway trolley to kill one person instead of five. Most people say yes. Far fewer would push a large man off a footbridge to stop the trolley, though the numbers are the same. Joshua Greene's brain imaging work suggests that up close personal harm triggers stronger emotional responses. These compete with cost benefit reasoning.

Fairness and the ultimatum game. One player gets 10 dollars and offers a split. The other can accept or reject. If they reject, both get nothing. A pure money maximizer would accept any offer. Real people often reject offers below about 20 to 30 percent. They pay to punish unfairness. Most proposers offer 40 to 50 percent. A 2003 brain imaging study found unfair offers activated the insula, an area tied to disgust and body states.

Group decisions

Groups can be smarter or dumber than individuals. In 1906 Francis Galton saw about 800 people guess the weight of an ox at a fair. The middle guess was within 1 percent of the true weight. This **wisdom of crowds** works when guesses are independent. Talking first can ruin it. **Group polarization** pushes a group toward a more extreme version of its starting view. **Groupthink** is when the wish for agreement silences doubts. Groups also tend to discuss facts everyone already knows and neglect facts only one person holds.

Expertise and intuition: Klein versus Kahneman

Gary Klein studied firefighters and nurses. He found they rarely compare options. They see a situation, recognize a pattern and act. He called this recognition primed decision making. Kahneman was more skeptical of gut feel. In 2009 they wrote a joint paper. They agreed that intuition can be trusted under two conditions. The environment must be regular enough to learn. And the person must have had lots of practice with quick, clear feedback. A chess master or an experienced anesthetist qualifies. A stock picker or a long range political forecaster usually does not.

How stress, sleep and hunger change choices

STATE	TYPICAL EFFECT ON CHOICE	STRENGTH OF EVIDENCE
Acute stress	Shifts behavior toward habits and away from goal directed control. Narrows attention	Fairly strong in lab studies
Sleep loss	More impulsive choices, worse risk judgment, more focus on gains	Moderate, findings vary
Hunger	Raises the value of food. May make people less patient for other rewards	Mixed
Decision fatigue	A 2011 study of Israeli parole judges found favorable rulings fell from about 65 percent to near zero before each break	**Debated.** Case ordering may explain much of it

Regret

Regret is the pain of seeing that another choice would have turned out better. Thomas Gilovich and Victoria Medvec found a time pattern. In the short term people regret actions more, like a rude remark. Over a lifetime they regret inactions more, like the course they never took. Fear of regret also shapes choices before they are made. People often stick with the default to avoid blaming themselves later.

Measurable signals

SIGNAL	WHAT IT TELLS YOU	TOOL
Choices in simple tasks	Risk taste, loss aversion, discounting	Short online choice tasks
Skin conductance before choices	Anticipatory arousal	Finger electrodes or wrist sensor
Pupil size	Effort and surprise	Eye tracker or camera
Reaction time	Fast versus deliberate choice	Computer or phone task
Sleep and activity	State that shifts choices	Wrist actigraphy, sleep tracker
Daily habits	What is automatic	Phone logs, location, experience sampling

Key takeaways

- Motivation starts with body drives and extends to needs for autonomy, competence and connection.
- Dopamine signals surprise about reward and drives wanting more than liking.
- Habits take weeks to months to form, not 21 days.
- Ego depletion did not replicate well. Avoiding temptation works better than resisting it.
- System 1 and System 2 are useful labels, not brain parts.
- Loss aversion is common but its size varies and is debated.
- Emotion is part of good choice. Intuition is trustworthy only with regular environments and fast feedback.

SOURCES AND FURTHER READING

- Schultz, W., Dayan, P., and Montague, P. R. (1997). A neural substrate of prediction and reward. *Science*. https://doi.org/10.1126/science.275.5306.1593
- Berridge, K. C., and Robinson, T. E. (1998). What is the role of dopamine in reward? *Brain Research Reviews*. https://doi.org/10.1016/S0165-0173(98)00019-8

- Ryan, R. M., and Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation. *American Psychologist*. https://doi.org/10.1037/0003-066X.55.1.68
- Kahneman, D., and Tversky, A. (1979). Prospect theory. *Econometrica*. https://doi.org/10.2307/1914185
- Hagger, M. S., et al. (2016). A multilab preregistered replication of the ego-depletion effect. *Perspectives on Psychological Science*. https://doi.org/10.1177/1745691616652873
- Kahneman, D., and Klein, G. (2009). Conditions for intuitive expertise: A failure to disagree. *American Psychologist*. https://doi.org/10.1037/a0016755
- Bechara, A., Damasio, H., Tranel, D., and Damasio, A. R. (1997). Deciding advantageously before knowing the advantageous strategy. *Science*. https://doi.org/10.1126/science.275.5304.1293
- Gal, D., and Rucker, D. D. (2018). The loss of loss aversion. *Journal of Consumer Psychology*. https://doi.org/10.1002/jcpy.1047

CHAPTER 09

Language, Thought and Imagination

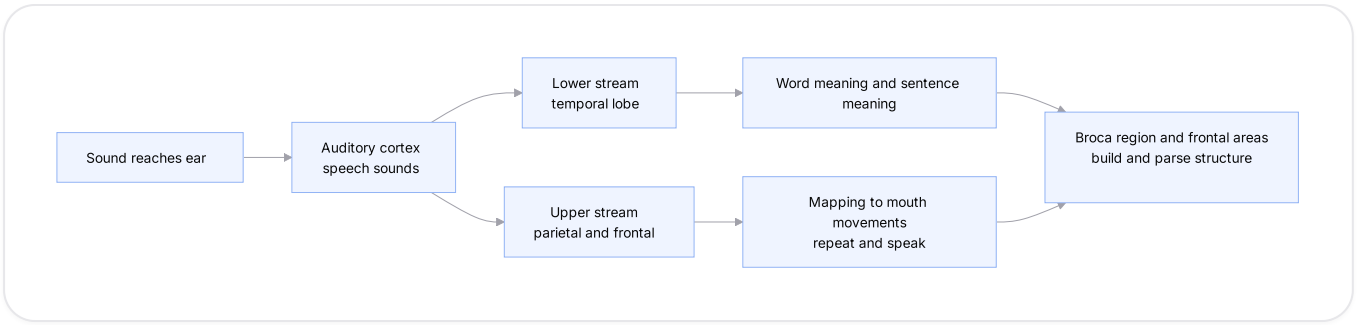
Language lets one mind change what is inside another mind using only sound, signs or marks on a page. Thought and imagination let a single mind travel to places and times it has never been. This chapter starts with how the brain handles language and how children pick it up with little teaching. It then asks whether the words you speak shape how you think. It moves on to concepts, reasoning, problem solving and insight. It ends with inner imagery, imagining the future, daydreaming, creativity, metaphor, humor, "what if" thinking, reading other minds through language and the large part of communication that is not words at all.

Language in the brain

In 1861 the French doctor Paul Broca studied a patient who could understand speech but could say only one syllable, "tan". After the man died Broca found damage in the lower left frontal lobe. This area became known as **Broca's area**. In 1874 Carl Wernicke described patients with the opposite problem. They spoke fluently but made little sense and struggled to understand others. Their damage was further back in the left temporal lobe. This became **Wernicke's area**. A bundle of fibers called the arcuate fasciculus links the two.

That classic picture was a good start but is now seen as far too simple. Modern brain imaging shows a wider **language network**. It sits mostly in the left frontal and temporal lobes in about 95 percent of right handed people. Gregory Hickok and David Poeppel proposed a **dual stream model**. A lower stream maps sounds to meaning. An upper stream maps sounds to the mouth movements that make them.

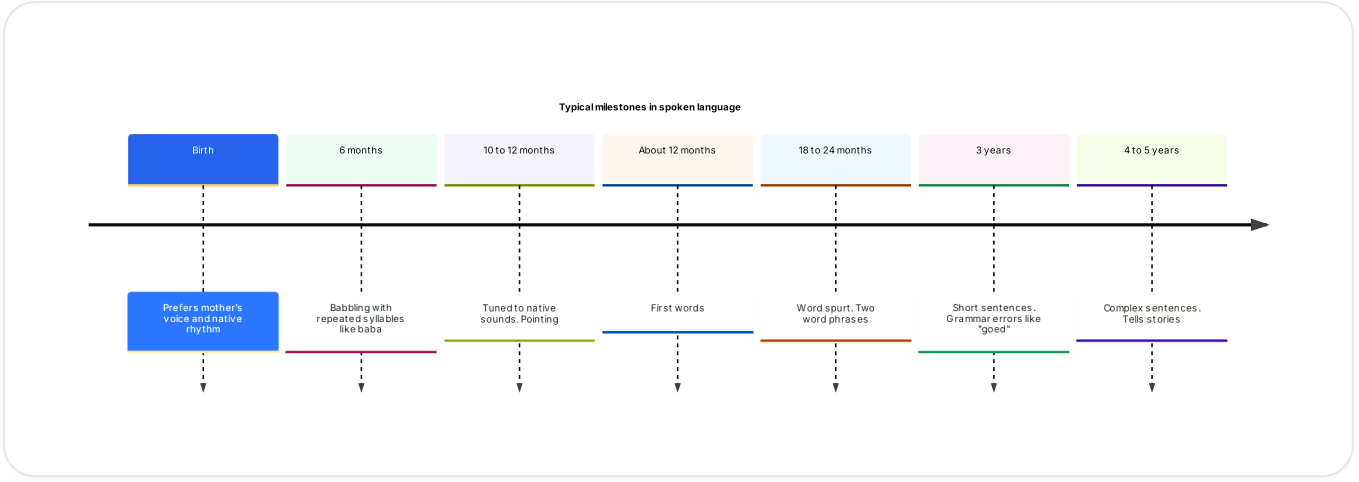
Evelina Fedorenko and colleagues have shown something surprising. The core language network is quite separate from the brain areas used for math, logic and music. Some people with severe aphasia, meaning loss of language after brain damage, can still do arithmetic and play chess. This suggests that language is a tool for passing thoughts between people. It is not the same thing as thought itself.



How children learn language

Babies start learning before birth. Newborns prefer their mother's voice and the rhythm of her language. Early on, infants can hear the sound differences used in any language. By around 10 to 12 months they get better at the sounds of their own language and worse at foreign ones. A Japanese baby loses easy access to the "r" versus "l" contrast. Patricia Kuhl calls this a perceptual narrowing.

Babies are statistical learners. In a 1996 study by Jenny Saffran and colleagues, 8 month olds heard two minutes of a made up stream of syllables with no pauses. Afterward they could tell which syllable groups formed "words". They did it by tracking which syllables tended to follow each other.



There is a long debate about how much of this is built in. Noam Chomsky argued that children have an inborn grammar that limits what languages can look like. Usage based researchers such as Michael Tomasello argue that general learning plus social skills like shared attention is enough. Most researchers agree there is a sensitive period. Children who get no language input early, such as some deaf children never exposed to sign, have lasting trouble with grammar. In the 1980s deaf children in Nicaragua who were brought together in new schools created a new sign language. It grew richer as each new group of younger children learned it.

Inner speech

Many people hear a voice in their head as they read, plan or argue with themselves. Lev Vygotsky argued that children's talking aloud to themselves while playing goes inward with age and becomes inner speech. Inner speech helps people plan, keep items in mind and control behavior. It varies a lot between people. Russell Hurlburt beeps people at random moments and asks what was in their mind. Inner speech shows up in roughly a quarter of samples on average. People who report little or no inner speech can still think well. They may think in images, feelings or without words at all.

Does language shape thought?

The idea that language shapes thought is called **linguistic relativity**. It is often linked with Benjamin Lee Whorf. It comes in two strengths.

VERSION	CLAIM	STATUS
Strong, linguistic determinism	Language fixes what you can think. Without a word you cannot have the concept	Largely rejected. People can think about things they lack words for
Weak	Language nudges attention, memory and speed of judgment	Supported by many studies, with effects often modest

Examples support the weak version. Russian has separate basic words for light blue and dark blue. In a 2007 study Russian speakers told these shades apart slightly faster than English speakers. The edge disappeared when they had to repeat numbers in their head, which blocks inner speech. Speakers of Guugu Yimithirr in Australia describe space with north, south, east and west, not left and right. They stay oriented in a way most English speakers do not. The Pirahã of the Amazon have no exact number words. They struggle to match large quantities exactly.

Concepts and categories

A concept is a mental grouping, like "bird" or "chair". The classical view said each concept has a set of necessary features. That fails for many everyday concepts. Philosopher Ludwig Wittgenstein noted there is no single feature shared by all games. In the 1970s Eleanor Rosch showed that categories have a **prototype**. That is a best example. A robin seems more "birdy" than a penguin. People answer faster for typical members. Rosch also found a **basic**

level that people use most. "Chair" is more natural than "furniture" or "kitchen chair". Other views say we store many specific examples, or that concepts rest on our beliefs about causes.

Reasoning

Deductive reasoning draws a conclusion that must be true if the premises are true. People are not very good at abstract logic. In the Wason card task only about 10 percent of people pick the right cards to test an abstract rule. Many more succeed when the same logic is framed as a social rule, like checking who is drinking alcohol under age.

Inductive reasoning goes from cases to a general rule that is likely but not certain. It is how most daily learning works.

Analogical reasoning maps the structure of one situation onto another. In a classic study people had to destroy a tumor with rays without harming healthy tissue. Few solved it. Then they read a story about an army that split up to attack a fortress from many roads at once. About 10 percent solved the ray problem without the story. With the story and a hint to use it, most did. Without the hint many still missed the link. Spotting the analogy is the hard part.

Problem solving and insight

Some problems yield to step by step search. Others need **insight**. That is a sudden restructuring, the "aha" moment. In Karl Duncker's candle problem people must fix a candle to a wall using a box of tacks. The trick is to use the box as a shelf. Many fail because they see the box only as a container. This is called **functional fixedness**. Stepping away for a while, called incubation, sometimes helps. Brain studies by John Kounios and Mark Beeman found a burst of fast brain activity over the right temporal lobe just before people reported an insight.

Mental imagery and aphantasia

Most people can "see" a picture in the mind. In 1971 Roger Shepard and Jacqueline Metzler asked people whether two 3D shapes were the same. The time to answer grew in step with how far one shape had to be rotated. This suggested people mentally rotate images. Vision areas of the brain become active during imagery too.

But not everyone has a mind's eye. In 2015 Adam Zeman and colleagues named **aphantasia**, the lack of voluntary visual imagery. Estimates suggest about 1 percent of people have none at all and about 3 to 4 percent have very weak imagery. At the other end, **hyperphantasia** is

imagery as vivid as real seeing. Many people with aphantasia only learn they are different as adults.

Mental time travel and the default mode network

Endel Tulving called the ability to relive the past and pre live the future **mental time travel**. Daniel Schacter and Donna Addis showed that imagining the future uses the same brain system as remembering. The brain takes pieces of memories and recombines them into new scenes. A 2007 study found that patients with damage to the hippocampus, a memory structure, struggled to imagine new scenes in rich detail. This helps explain why memory is built for recombining, not exact replay.

The brain regions active during remembering, imagining and daydreaming form the **default mode network**. It includes the middle of the frontal lobe, the posterior cingulate and parts of the parietal and temporal lobes. A 2010 study pinged about 2,250 people on their phones. Their minds were wandering in about 47 percent of samples. People were less happy when their minds wandered, even to pleasant topics. **The direction of cause is debated.** Unhappy people may also wander more. Mind wandering also supports planning and creative ideas.

Creativity, metaphor, humor and "what if"

Creativity is producing something both new and useful. Researchers separate **divergent thinking**, generating many ideas, from **convergent thinking**, finding the one best answer. A common test asks for as many uses for a brick as possible. Brain imaging by Roger Beaty and colleagues suggests creative people show stronger links between the default mode network, which generates ideas, and the executive control network, which judges them.

Metaphor is understanding one thing in terms of another. George Lakoff and Mark Johnson argued that much everyday thought is built on body based metaphors. We speak of "high" status, "warm" people and "grasping" an idea. Some studies claimed physical warmth makes people judge others as warmer. Several of those effects **failed to replicate**. The language patterns are real. Their power to steer behavior is less certain.

Humor often comes from an incongruity that suddenly makes sense in a new way. The benign violation theory adds that something feels funny when it breaks a rule but in a harmless way. Robert Provine found that most laughter in daily talk follows ordinary remarks, not jokes. Laughter is mainly a social signal.

Counterfactual thinking is imagining how things could have gone differently. Upward ones ("if only I had left earlier") hurt but teach. Downward ones ("at least nobody was hurt")

comfort. In a 1995 study of Olympic athletes, bronze medalists looked happier than silver medalists. Silver winners compared themselves to gold. Bronze winners compared themselves to no medal.

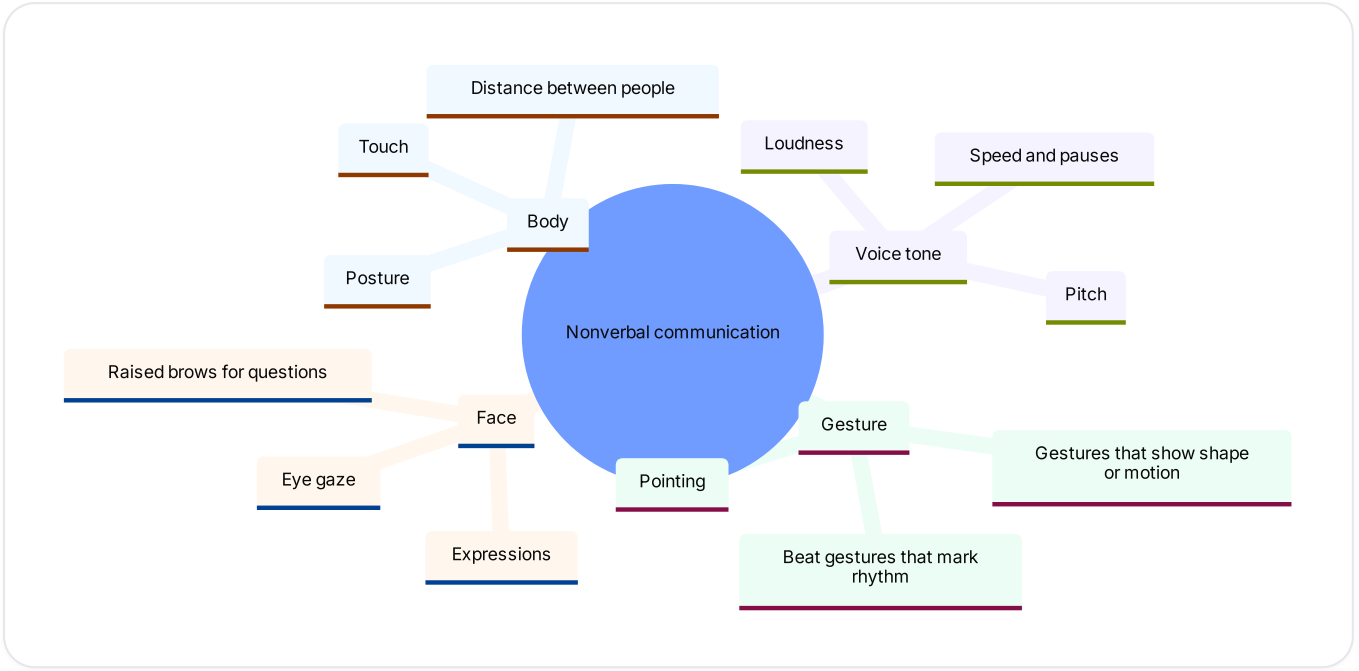
Theory of mind in language

Theory of mind is the ability to think about what others believe, want and know. In false belief tasks a child sees a puppet hide a marble. The puppet leaves and the marble is moved. Where will the puppet look? Most children pass these tasks around age 4 to 5. Children who hear more talk about thoughts and feelings, words like "think" and "know", tend to pass earlier. Deaf children of hearing parents who get late access to sign language often pass later.

Daily language depends on mind reading. If someone says "it's cold in here" they may be asking you to close the window. Philosopher Paul Grice described how listeners infer such hidden meanings by assuming the speaker is being cooperative.

Nonverbal communication

People constantly send signals beyond words.



Gestures are tightly linked to speech. People gesture even on the phone and blind people gesture too. Susan Goldin-Meadow found that children's hands sometimes show an idea

before their words do. Tone of voice, called prosody, carries emotion and marks questions, sarcasm and emphasis.

A popular claim says that 93 percent of communication is nonverbal. **This is a myth.** Albert Mehrabian's 1960s studies used single words spoken in a tone that clashed with their meaning. They were never meant to apply to all communication. In real talk the words matter a great deal. Nonverbal cues matter most when they conflict with the words or when people judge emotions and attitudes.

Measurable signals

SIGNAL	WHAT IT TELLS YOU	TOOL
Word choice and vocabulary	Style, concepts, emotion words used	Text samples, transcripts of speech
Speech rhythm and pitch	Emotion, certainty, sarcasm	Microphone and voice analysis
Inner experience	Inner speech, imagery, mind wandering	Random beeper sampling, questionnaires such as the Vividness of Visual Imagery Questionnaire
Gesture and gaze	Engagement, thinking, turn taking	Video camera, eye tracker
Brain activity during language or rest	Language network, default mode network	fMRI, EEG
Reasoning and creativity	Logical and divergent thinking style	Standard tasks like the Wason task and uses for a brick

Key takeaways

- Language relies on a left side network much wider than Broca's and Wernicke's areas. It is separate from areas used for math and logic.
- Children learn language through statistics, social attention and a sensitive window early in life.
- Language nudges thought in modest ways. It does not cage it.
- Imagining the future reuses memory. The default mode network supports remembering, imagining and daydreaming.
- People differ a lot in inner speech and mental imagery. Some have none.
- Mind reading is built into everyday language. Much meaning is implied, not said.
- The "93 percent nonverbal" claim is a myth. Words and nonverbal cues work together.

SOURCES AND FURTHER READING

- Hickok, G., and Poeppel, D. (2007). The cortical organization of speech processing. *Nature Reviews Neuroscience*. https://doi.org/10.1038/nrn2113
- Fedorenko, E., Ivanova, A. A., and Regev, T. I. (2024). The language network as a natural kind within the broader landscape of the human brain. *Nature Reviews Neuroscience*. https://doi.org/10.1038/s41583-024-00802-4
- Kuhl, P. K. (2004). Early language acquisition: Cracking the speech code. *Nature Reviews Neuroscience*. https://doi.org/10.1038/nrn1533
- Saffran, J. R., Aslin, R. N., and Newport, E. L. (1996). Statistical learning by 8-month-old infants. *Science*. https://doi.org/10.1126/science.274.5294.1926
- Alderson-Day, B., and Fernyhough, C. (2015). Inner speech. *Psychological Bulletin*. https://doi.org/10.1037/bul0000021
- Winawer, J., et al. (2007). Russian blues reveal effects of language on color discrimination. *PNAS*. https://doi.org/10.1073/pnas.0701644104
- Schacter, D. L., and Addis, D. R. (2007). The cognitive neuroscience of constructive memory. *Philosophical Transactions of the Royal Society B*. https://doi.org/10.1098/rstb.2007.2087
- Zeman, A., Dewar, M., and Della Sala, S. (2015). Lives without imagery: Congenital aphantasia. *Cortex*. https://doi.org/10.1016/j.cortex.2015.05.019

CHAPTER 10

Connection: The Social Human

Humans are among the most social animals on Earth. Our brains grew large partly to keep track of other people. We are born helpless and survive only through bonds with caregivers, and the style of those first bonds echoes through adult love. Hormones like oxytocin and endorphins help glue relationships together, though their power has been oversold. We read other minds, feel other people's pain, copy our group and punish cheaters. Being cut off from others is not just sad. It is a real health risk. And close relationships literally tune the body: two people who trust each other calm each other's hearts and stress systems. This chapter explains how all of that works and where the science is still argued over.

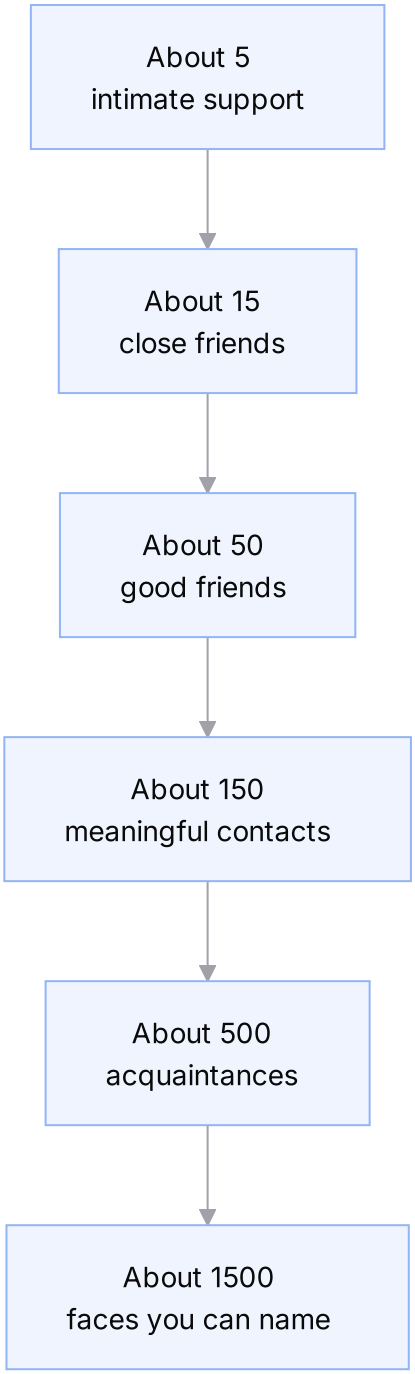
Why humans are ultra social

A lone human in the wild does poorly. What we have is each other. Group life brings big rewards and big puzzles. You must remember who helped you, who cheated, who is allied with whom and what each person knows.

The **social brain hypothesis**, put forward by Robin Dunbar in the 1990s, says this social puzzle drove brain growth in primates. Across primate species, the relative size of the neocortex (the wrinkled outer layer of the brain) tracks average group size better than it tracks diet or territory size. Bigger social worlds seem to need more brain.

From that line Dunbar predicted that humans can keep about **150** stable relationships. This is **Dunbar's number**. He also described rough layers of closeness, shown below. Hunter gatherer clans, Neolithic villages and military companies often sit near 150.

The number is **debated**. A 2021 re-analysis by Lindenfors and colleagues used newer statistics on the same kind of primate data. Their estimates for humans ranged from a handful to more than 500, so wide that no single number stands out. Critics also note that brain size is shaped by diet, life span and many other factors. A fair summary is that people do have a limited social capacity, and layered circles of closeness are real, but "150" is a rough rule of thumb, not a law.



Attachment: the first bond

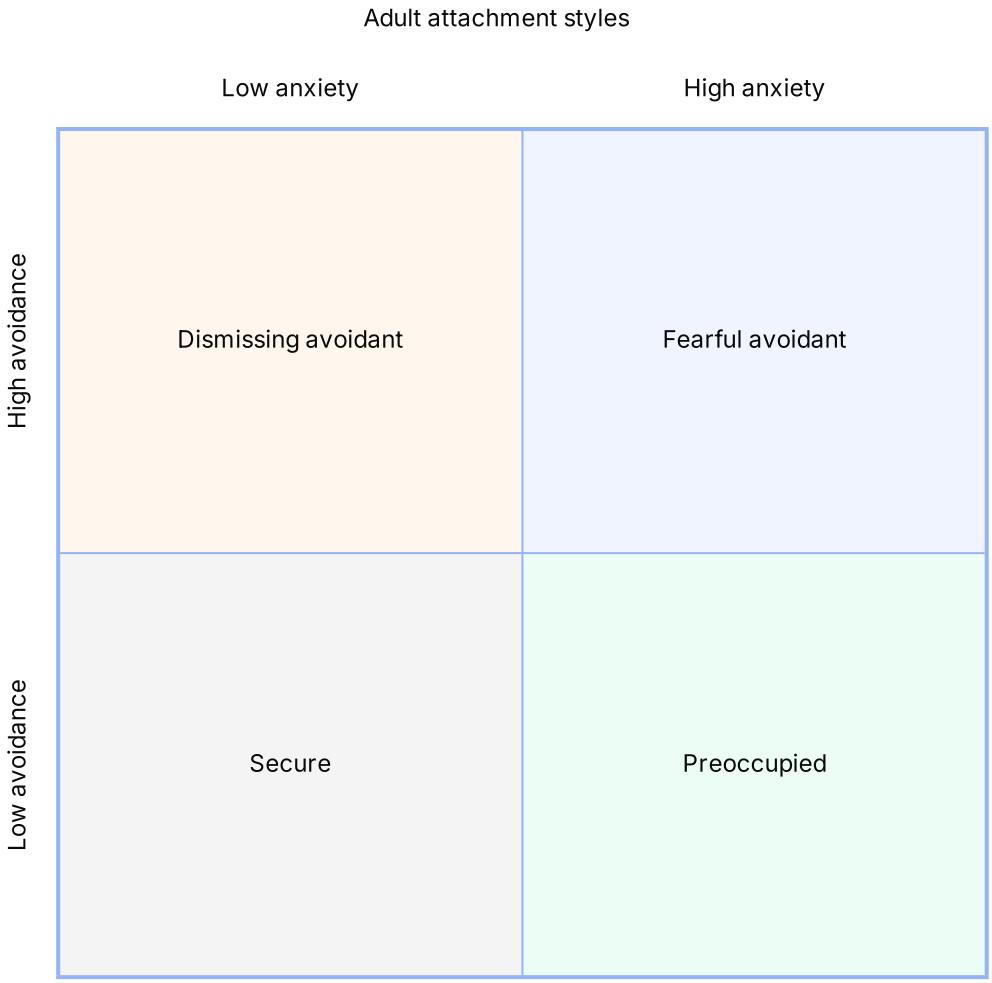
John Bowlby, a British psychiatrist, argued in the 1950s and 1960s that babies are born with an **attachment system**. It is a built-in drive to stay near a caregiver, especially when scared, sick or tired. The caregiver becomes a "secure base" to explore from and a "safe haven" to return to. This was a radical claim at a time when many experts thought babies loved mothers only because mothers fed them.

Mary Ainsworth tested this with the **Strange Situation**, a 20 minute lab routine for 12 to 18 month olds. The baby plays with the parent, a stranger enters, the parent leaves twice and returns twice. What matters most is the reunion.

PATTERN	WHAT THE BABY DOES AT REUNION	TYPICAL SHARE IN LOW RISK SAMPLES
Secure	Seeks the parent, is soothed, goes back to play	About 60 to 65%
Avoidant	Ignores or turns away, though the body is stressed	About 20%
Resistant (ambivalent)	Clings but also pushes away, hard to soothe	About 10 to 15%
Disorganized	Freezes, odd or conflicting moves	Added later by Main and Solomon; higher in high risk samples

Avoidant babies look calm, but studies of heart rate and cortisol (a stress hormone) show their bodies are aroused. They have learned to hide their need.

In 1987 Hazan and Shaver showed that adult romantic love has the same patterns. Today adult attachment is usually measured on two scales. **Anxiety** is fear of being abandoned. **Avoidance** is discomfort with closeness. Your place on the two scales gives your style.



Two caveats matter. First, attachment style is only moderately stable from infancy to adulthood. Life events like divorce, loss or a loving partner can shift it. Second, these are dimensions, not boxes. Most people sit somewhere in between and can act differently with a mother than with a spouse.

Bonding chemistry and the oxytocin hype

Oxytocin is a small hormone made in the hypothalamus. Its firm, well proven jobs are physical. It drives contractions in labor and the milk letdown reflex in breastfeeding. In prairie voles, which form lifelong pair bonds, blocking oxytocin or **vasopressin** (a closely related hormone) receptors stops bonding. Their close cousins, the promiscuous meadow voles, have different receptor patterns in reward areas of the brain.

This led to headlines calling oxytocin the "love hormone" or "cuddle chemical". A 2005 study found that a nasal spray of oxytocin made people trust strangers more with money. That finding has **not replicated well**. A 2015 review by Nave, Camerer and McCullough found that

many sprayed oxytocin studies were small, that failed repeats were common, and that it is unclear how much sprayed oxytocin even reaches the brain. Effects also depend on context. Oxytocin can increase favoritism toward your own group and defensiveness toward outsiders. The better view is that oxytocin makes social cues more salient, for better or worse, rather than making people kind.

Endorphins are the body's own opioids. Dunbar and others argue they are the main glue for wider friendships. Grooming in monkeys, and laughing, singing, dancing and rowing together in humans, raise pain tolerance, which is an indirect sign of endorphin release. Brain scans with tracers that bind opioid receptors show endorphin release during social laughter. **Dopamine**, the brain's "wanting" signal, adds the craving and reward side of attachment.

Love: passionate and companionate

Psychologist Elaine Hatfield split romantic love into two kinds. **Passionate love** is intense longing, obsessive thinking and craving. **Companionate love** is deep friendship, trust and comfort. Brain scans by Helen Fisher, Arthur Aron and others show that people in early passionate love activate dopamine rich reward areas when they see a photo of their partner, much as in craving. Passion usually fades over the first few years while companionate love can grow. Some long married couples still show that reward response, so fading is common but not universal.

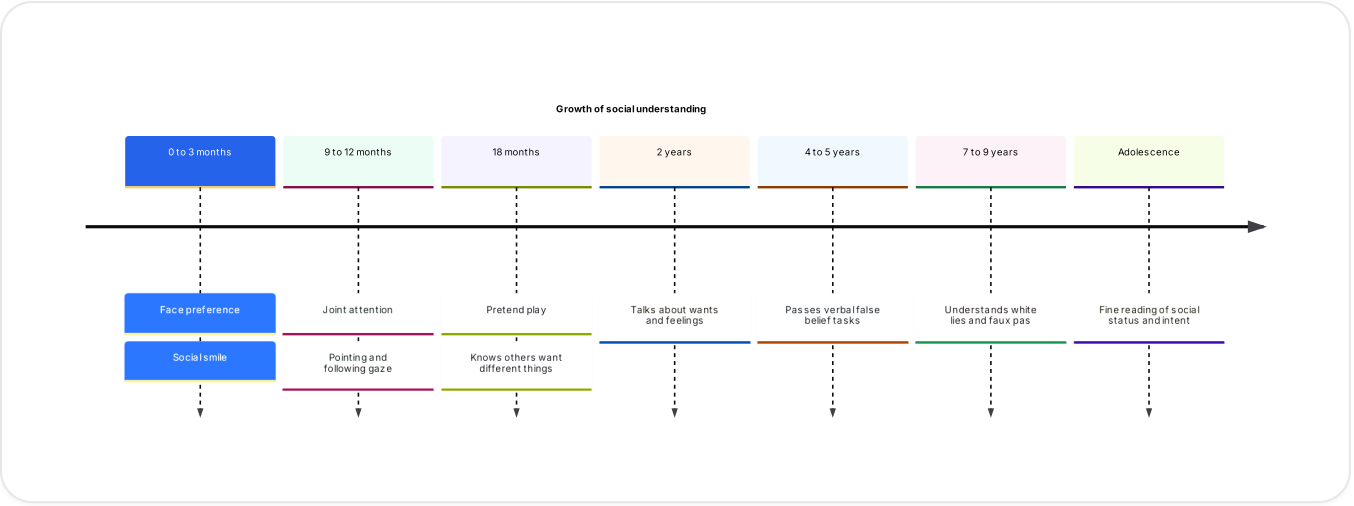
Empathy, mirror neurons and theory of mind

Empathy has two main parts. **Affective empathy** is feeling what another feels, like wincing when a friend stubs a toe. **Cognitive empathy** is understanding what another feels or thinks without necessarily sharing it. A good negotiator may have high cognitive and low affective empathy. A burned out nurse may have the opposite problem. When people watch a loved one in pain, parts of their own pain network, such as the anterior insula and anterior cingulate cortex, light up.

Mirror neurons were found in macaque monkeys in Parma in the 1990s. They fire both when a monkey grabs a peanut and when it watches someone else grab one. They were soon hailed as the root of empathy, language and culture, with autism blamed on "broken mirrors". This was **hype**. Direct recordings from single human neurons are rare. Evidence that mirror systems explain empathy or autism is weak. Most researchers now see them as one useful piece of action understanding, not the key to the social mind.

Theory of mind is the ability to understand that others have beliefs, wishes and knowledge that differ from yours. The classic test is the **false belief task**. In the Sally Anne version, Sally

puts a marble in a basket and leaves. Anne moves it to a box. Where will Sally look? Most 3 year olds say the box, where it really is. Most 4 to 5 year olds say the basket, because Sally does not know it moved. Studies that track where babies look suggest some implicit grasp of false belief by 15 months or even earlier. Those infant findings are **debated** because several replications failed.



Social pain and loneliness

Being left out hurts in a way that resembles physical pain. In the "Cyberball" game, a person is tossed a virtual ball and then excluded. Brain scans show activity in regions also involved in pain distress, though how much the two overlap is debated.

The health effects are large. In 2010 Julianne Holt-Lunstad and colleagues pooled 148 studies with about 309,000 people. People with stronger social ties had about **50% higher odds of survival** over the follow up periods. A 2015 follow up found that social isolation, loneliness and living alone each raised the risk of death by about 26 to 32%. The often quoted claim that loneliness is "as bad as smoking 15 cigarettes a day" comes from comparing these effect sizes with smoking effect sizes. It is a striking way to say the effect is big. It is not a precise equivalence, and the studies are observational, so some of the link could run the other way, from illness to isolation.

How could loneliness hurt the body? Lonely people show more vigilance for social threat, worse sleep, higher blood pressure and more inflammation. Isolation also removes practical help, like someone who notices you are ill.

Synchrony: bodies and brains in step

People who interact tend to fall into rhythm. Couples' heart rates and breathing patterns can align. At a fire walking ritual in Spain, the heart rates of walkers and their watching relatives rose and fell together, but strangers did not sync. Mothers and babies sync their gaze, voice rhythm and even heart rhythms during face to face play.

Brains sync too. Uri Hasson and colleagues showed that when one person tells a story and another listens, their brain activity patterns couple, with the listener lagging a few seconds behind. The stronger the coupling, the better the listener understood. Moving in sync, like marching or dancing, increases later liking and cooperation in lab studies.

Trust, cooperation, fairness and morality

Humans cooperate with unrelated strangers at a scale no other animal matches. Lab games reveal the rules. In the **ultimatum game**, one person splits money and the other can accept or reject. If they reject, both get nothing. Pure self interest says accept any offer. Yet people in many societies reject offers below about 20 to 30%. They pay to punish unfairness. Studies in 15 small scale societies found that what counts as a fair offer varies with how much a culture relies on markets and cooperation.

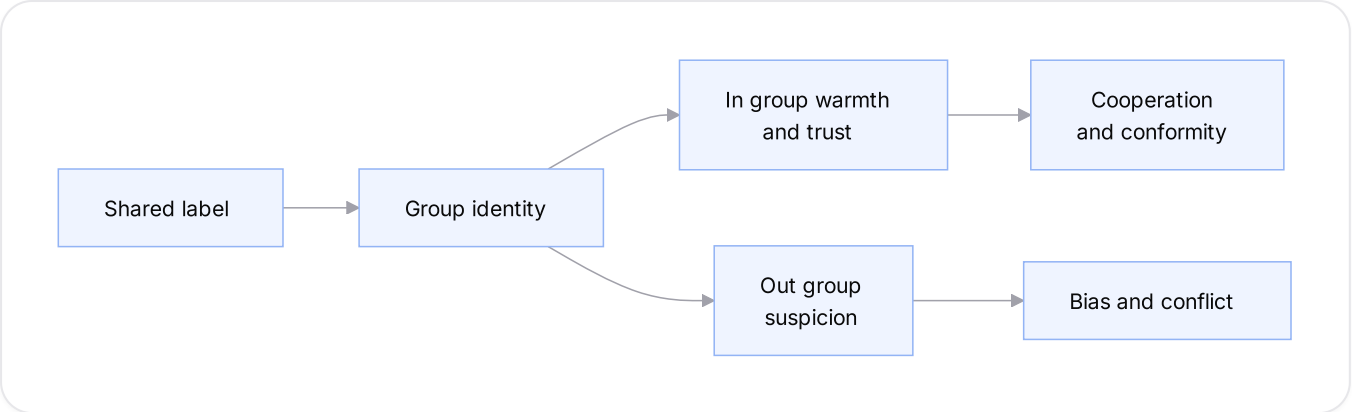
Jonathan Haidt's **moral foundations theory** proposes several intuitive moral "taste buds": care, fairness, loyalty, authority, sanctity and later liberty. It suggests political liberals lean on care and fairness while conservatives use all foundations more evenly. The theory is **debated**. Critics question whether the foundations are really separate, whether the survey replicates across cultures, and whether harm might underlie all of them. Most agree that moral judgments are often fast feelings that reasoning later justifies.

Culture, groups and conformity

Children **over-imitate**. They copy even the useless steps an adult shows them, which chimps skip. This helps pass on tools and rituals whose logic is hidden. Culture then shapes the mind itself. Henrich, Heine and Norenzayan warned in 2010 that most psychology studies use **WEIRD** people (Western, Educated, Industrialized, Rich, Democratic), who are often outliers on fairness, visual illusions and sense of self.

Group identity forms with frightening ease. In Henri Tajfel's **minimal group** studies in the 1970s, boys split by a trivial label, such as liking one painter over another, gave more to their own group. Solomon Asch in the 1950s asked people to match line lengths after actors gave wrong answers. About a third of answers on test trials followed the wrong majority, and

about three in four people conformed at least once. Yet a single ally who gave the right answer cut conformity sharply.



Touch and co-regulation

The skin has special nerve fibers called **C-tactile afferents**. They respond best to slow gentle stroking at about 1 to 10 cm per second, the speed of a caress, and feed emotional brain areas. Skin to skin contact helps premature babies keep stable temperature and heart rate.

In a well known study by Jim Coan and colleagues, women in a brain scanner faced the threat of a mild electric shock. Holding their husband's hand reduced threat related brain activity more than holding a stranger's hand. The effect was strongest in the happiest marriages. Coan calls this **social baseline theory**. The brain expects to have others nearby and spends less energy on threat when they are. This is **co-regulation**: partners, parents and friends help keep each other's heart rate, breathing, cortisol and mood in range. Infants cannot regulate alone at all. Adults can, but it costs more.

Measurable signals

SIGNAL	WHAT IT REFLECTS	TOOL USED ON A LIVING PERSON
Attachment anxiety and avoidance	Adult attachment style	ECR-R questionnaire, Adult Attachment Interview
Size and layers of social network	Social capacity and support	Network interviews, phone call and message logs
Loneliness	Felt isolation	UCLA Loneliness Scale
Heart rate and breathing synchrony	Physical attunement between two people	Paired ECG or chest band recording
Brain coupling	Shared understanding in talk	Hyperscanning with fMRI, EEG or fNIRS
Empathy	Affective and cognitive empathy	Interpersonal Reactivity Index, emotion recognition tests
Theory of mind	Mental state reading	False belief tasks, Reading the Mind in the Eyes test
Fairness and trust	Social decision style	Ultimatum, dictator and trust games
Inflammation linked to isolation	Body cost of loneliness	Blood CRP and IL-6 levels

Key takeaways

- The social brain hypothesis links primate brain size to group life. Dunbar's number of about 150 is a useful rough guide but is statistically debated.
- Attachment styles start in infancy and show up in adult love along two dimensions, anxiety and avoidance. They can change.
- Oxytocin is real and important in birth and bonding in animals, but the "love hormone" story and sprayed oxytocin results are weak.
- Empathy has feeling and thinking parts. Mirror neurons were overhyped. Theory of mind is clearly in place by age 4 to 5.
- Social isolation and loneliness predict earlier death by roughly 26 to 50% in large pooled studies. The smoking comparison is a vivid summary, not an exact match.
- People sync hearts and brains, punish unfairness, favor their group, conform and calm each other's bodies through touch and presence.

SOURCES AND FURTHER READING

- Holt-Lunstad, J., Smith, T. B., and Layton, J. B. (2010). Social relationships and mortality risk: a meta-analytic review. *PLoS Medicine*. https://doi.org/10.1371/journal.pmed.1000316
- Holt-Lunstad, J., et al. (2015). Loneliness and social isolation as risk factors for mortality. *Perspectives on Psychological Science*. https://doi.org/10.1177/1745691614568352
- Lindenfors, P., Wartel, A., and Lind, J. (2021). Dunbar's number deconstructed. *Biology Letters*. https://doi.org/10.1098/rsbl.2021.0158
- Hazan, C., and Shaver, P. (1987). Romantic love conceptualized as an attachment process. *Journal of Personality and Social Psychology*. https://doi.org/10.1037/0022-3514.52.3.511
- Nave, G., Camerer, C., and McCullough, M. (2015). Does oxytocin increase trust in humans? A critical review of research. *Perspectives on Psychological Science*. https://doi.org/10.1177/1745691615600138
- Coan, J. A., Schaefer, H. S., and Davidson, R. J. (2006). Lending a hand: social regulation of the neural response to threat. *Psychological Science*. https://doi.org/10.1111/j.1467-9280.2006.01832.x
- Hasson, U., et al. (2012). Brain-to-brain coupling: a mechanism for creating and sharing a social world. *Trends in Cognitive Sciences*. https://doi.org/10.1016/j.tics.2011.12.007
- Henrich, J., Heine, S. J., and Norenzayan, A. (2010). The weirdest people in the world? *Behavioral and Brain Sciences*. https://doi.org/10.1017/S0140525X0999152X

CHAPTER 11

Personality, Identity and the Life Span

Each person has a recognizable style of feeling, thinking and acting. Psychologists describe it with a few broad traits, measured reliably and partly inherited. Those traits start as infant temperament, settle over adulthood and still keep changing in small ways into old age. On top of traits sits identity: the values we hold and the life story we tell about ourselves. Underneath sits the body. Sleep, body clocks, stress, gut, exercise, food, hormones and inflammation color our mood and thinking every single day. This chapter covers who a person is, how that changes from birth to old age, and the physical rhythms that shape the daily mind. It ends with natural variation between minds, such as autism, ADHD, introversion and sensitivity.

Traits: the Big Five and HEXACO

If you collect every adjective people use to describe each other and look at which ones go together, a few big clusters keep appearing. This "lexical approach" produced the **Big Five**, often remembered as OCEAN.

TRAIT	HIGH SCORERS TEND TO BE	LOW SCORERS TEND TO BE	EVERYDAY EXAMPLE
Openness to experience	Curious, imaginative, drawn to art and new ideas	Practical, conventional	Orders the unknown dish on the menu
Conscientiousness	Organized, reliable, self disciplined	Spontaneous, careless	Pays bills before they are due
Extraversion	Talkative, energetic, seeks company	Quiet, reserved	Feels recharged after a party
Agreeableness	Warm, cooperative, trusting	Blunt, competitive, skeptical	Lets the other driver merge
Neuroticism	Prone to worry, sadness, mood swings	Calm, emotionally stable	Lies awake replaying an awkward comment

Each trait is a smooth scale, not a type. Most people sit near the middle. The traits predict real outcomes. Conscientiousness predicts grades, job performance and even longer life. Neuroticism predicts risk for anxiety and depression.

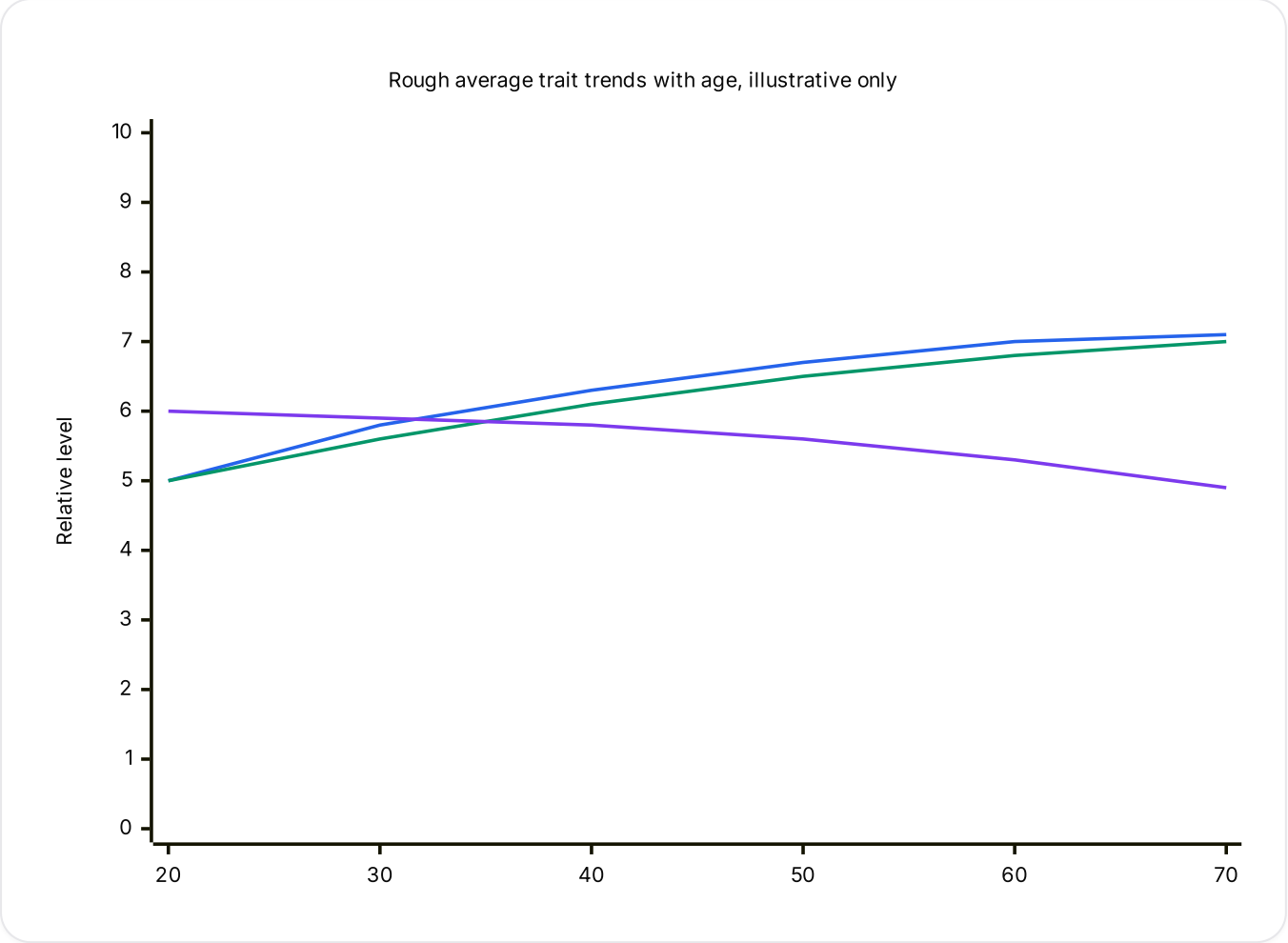
HEXACO is a six factor rival developed by Kibeom Lee and Michael Ashton from studies across many languages. It adds **Honesty Humility**, which covers sincerity, fairness, modesty and lack of greed. It also reshapes agreeableness and emotionality a little. Honesty Humility predicts cheating, exploiting others and workplace misconduct better than the Big Five does. Both models are well supported. Which is "right" is still **debated**, and they overlap heavily.

Traits are measured mostly with questionnaires, either about yourself or filled in by people who know you well. Ratings by close friends often predict behavior as well as self ratings, and sometimes better for traits that others can see.

Stability and change

Two kinds of stability matter. **Rank order stability** asks whether the most extraverted person at 20 is still among the most extraverted at 50. The answer is mostly yes, and stability rises with age, peaking around age 50 to 70. **Mean level change** asks whether people on average shift. Here a large 2006 meta-analysis by Roberts, Walton and Viechtbauer found steady

change well into adulthood. On average people become more conscientious, more agreeable and more emotionally stable from their 20s to their 60s. Researchers call this the **maturity principle**. Openness and social energy tend to dip in old age.



Top line: conscientiousness. Middle line: emotional stability. Falling line: openness. The shapes follow Roberts and colleagues; the exact heights are illustrative.

Life roles drive some of this. A first serious job or a committed relationship tends to come with a rise in conscientiousness and stability.

Genes, environment and temperament

Twin studies show that roughly **40 to 50%** of the differences between people in each Big Five trait are linked to genetic differences. That is "heritability". It describes a population, not a person. It does not mean half of your shyness came from your genes. Studies that scan the whole genome find thousands of tiny effects, each too small to notice alone, and so far they capture much less of the variation than twin studies suggest. This gap is called the "missing heritability".

Surprisingly, the environment that matters is mostly the **non-shared** environment. Growing up in the same household makes siblings only slightly more alike in personality. Different friends, teachers, accidents, illnesses and random chance during brain growth matter more.

Personality starts as **temperament**: inborn styles of reacting seen in the first months of life. Jerome Kagan studied **behaviorally inhibited** infants. These babies cry and thrash at new toys and faces at 4 months, and they are more likely to be shy and cautious as children. Many inhibited babies grow out of extreme shyness, especially with gentle encouragement. Modern models describe three temperament dimensions: negative emotionality, surgency (eager, active approach) and effortful control (self control). These map loosely onto adult neuroticism, extraversion and conscientiousness.

Identity, values and the narrative self

Traits describe how you tend to act. They do not tell your story. Psychologist Dan McAdams describes personality in three layers: traits, then **characteristic adaptations** like goals, values and coping habits, then the **narrative identity**. That is the evolving life story a person tells to explain how they became who they are. Some people tell "redemption" stories where bad events lead to growth. Others tell "contamination" stories where good things turn sour. Redemption stories are linked to better well being. Life stories take shape in adolescence, when teens first link past events into a coherent "me".

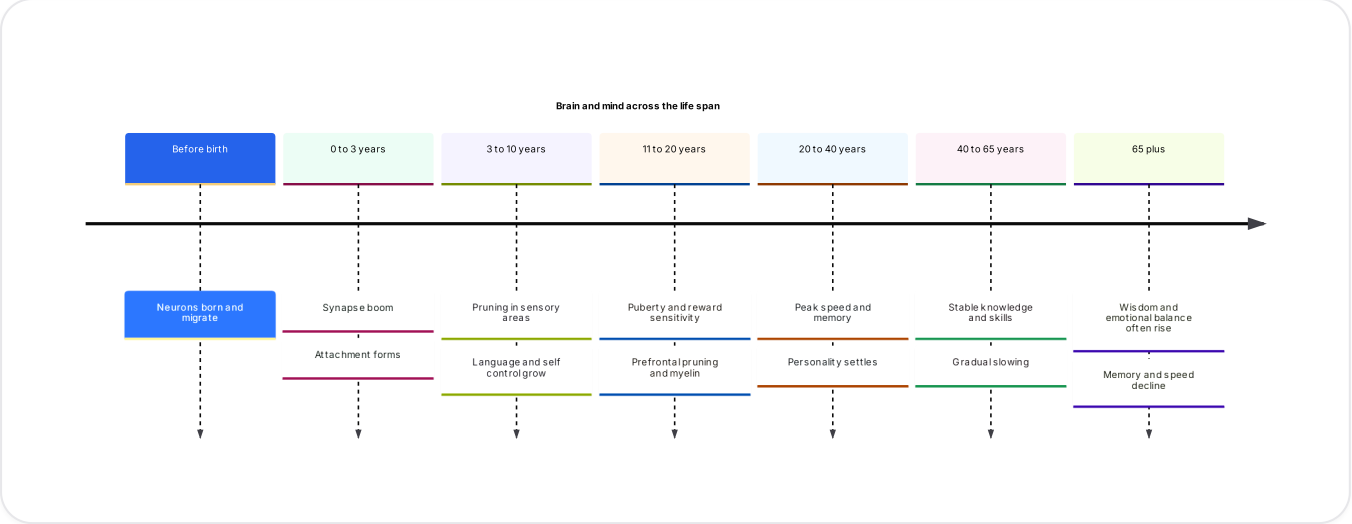
Values are deep goals that guide choices. Shalom Schwartz mapped about ten basic values that appear across dozens of countries, from security and tradition to achievement, self direction and caring for others. They are arranged in a circle where neighbors are compatible and opposites conflict, as when tradition pulls against stimulation. Beliefs often protect identity, which is why facts that threaten a group identity are so often resisted.

From birth to old age

The brain grows fastest before birth and in the first years. A newborn brain is about a quarter of adult size, and by age 6 it is about 90%. In the first years the brain makes synapses (connections between neurons) far faster than it needs. Then it **prunes** them, keeping connections that are used and removing the rest. Pruning happens earlier in sensory areas and later in the prefrontal cortex, the front region for planning and self control. **Myelin**, the fatty coating that speeds signals, keeps building into the 20s and beyond.

Adolescence brings a mismatch. Reward systems become very sensitive at puberty, while self control networks mature more slowly. Teens can reason as well as adults in calm settings. In heated moments and in front of peers they take more risks. In one driving game,

teens took more risks when friends were watching, but adults did not. The "the brain is done at 25" claim is a simplification. Different measures mature at different times, and change continues for life.



Brain volume peaks around early adulthood and then shrinks slowly. Different abilities peak at very different ages. A 2015 study by Hartshorne and Germine using large online samples found processing speed peaks near age 18 to 19. Short term memory for names peaks in the early 20s, and for faces in the early 30s. Vocabulary may not peak until the late 60s or early 70s. So "fluid" abilities, meaning fast novel problem solving, decline from early adulthood. "Crystallized" abilities, meaning knowledge and skill, hold or grow.

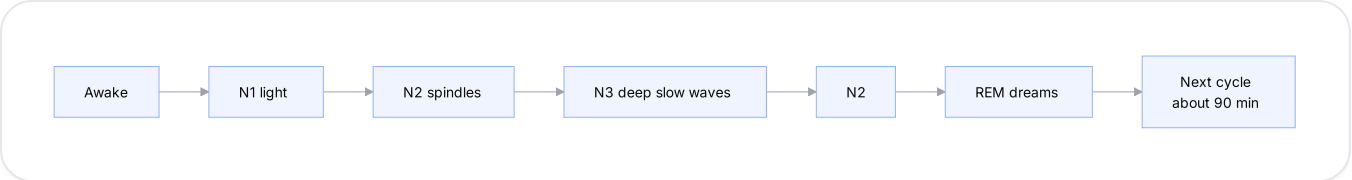
Several things often **improve** with age. Older adults tend to report more stable and positive daily moods. Laura Carstensen calls this the **positivity effect** and links it to a shorter sense of future time, which makes people focus on what matters emotionally. Skills in solving social conflicts, a part of wisdom, often rise too. Normal aging is not dementia. Dementia is a disease, and many people reach 90 with sharp minds.

The body behind the daily mind

SLEEP

Sleep runs in cycles of about 90 minutes. Each cycle passes through light **N1** and **N2** sleep, deep slow wave **N3** sleep and **REM** sleep, the stage with vivid dreams and paralyzed muscles. Deep sleep dominates early in the night and REM dominates near morning. Sleep helps lock in memories and resets emotional reactions. After one bad night, the amygdala, an alarm center of the brain, overreacts to unpleasant pictures. Adults need about 7 to 9 hours.

Losing sleep raises irritability, lowers attention and makes people worse at judging their own impairment.



CIRCADIAN RHYTHMS AND CHRONOTYPES

A master clock in the hypothalamus, the **suprachiasmatic nucleus**, keeps a rhythm of about 24.2 hours in most people. Morning light resets it each day. It times body temperature, cortisol, melatonin and alertness. People differ in **chronotype**. "Larks" peak early and "owls" peak late, partly due to genes. Teens shift later, and older adults shift earlier. **Social jet lag**, the gap between your body clock and your work schedule, is linked to worse mood and health.

STRESS

The stress response has two arms. The fast one is the sympathetic nervous system, releasing adrenaline in seconds. The slow one is the **HPA axis** (hypothalamus, pituitary, adrenal glands), releasing cortisol over minutes. **Acute stress** is useful. It sharpens focus and mobilizes energy for a deadline or danger. **Chronic stress** is different. Bruce McEwen called the cumulative wear and tear **allostatic load**. Constant high cortisol can disrupt sleep, raise blood pressure and blood sugar, weaken some immune functions and shrink connections in the hippocampus (a memory hub) and prefrontal cortex in animal studies.

GUT, EXERCISE AND FOOD

The gut and brain talk through the vagus nerve, hormones, immune signals and chemicals made by gut microbes. Mice raised germ free show altered stress responses. Transferring gut microbes from depressed people into rodents can change rodent behavior. About 90% of the body's serotonin is made in the gut, but it does not cross into the brain. Human evidence is **still early**. Most human studies are small or show links, not causes. "Psychobiotic" probiotic supplements have shown only small, inconsistent mood effects.

Exercise has much stronger evidence. In a one year trial with older adults, walking grew the hippocampus by about 2%, while a stretching group lost volume. Exercise reliably eases mild to moderate depression and anxiety. For nutrition, a Mediterranean style diet is linked to

lower depression risk, and one small trial (SMILES, 2017) found diet coaching helped depression. These findings need larger tests.

HORMONES AND INFLAMMATION

Hormones shift across life and across the month. In the menstrual cycle, estrogen rises before ovulation and progesterone rises after it. Most people feel only small changes. About 3 to 8% of menstruating people have **premenstrual dysphoric disorder**, a severe mood reaction to normal hormone shifts. Pregnancy, the time after birth and perimenopause are windows of higher depression risk. Testosterone in men falls slowly, about 1% per year from middle age, with wide variation.

When you have the flu you feel slow, sad and want to be alone. This **sickness behavior** is caused by immune signals called cytokines acting on the brain. It helps you rest. If inflammation stays high, it may feed depression. Some patients given the immune drug interferon alpha develop depression. People with depression on average have modestly higher inflammation markers like CRP, though only a subset show it.

Individual differences: neurodiversity, introversion and sensitivity

Neurodiversity is the idea that brain differences like autism and ADHD are natural variations with strengths and challenges, not only disorders. **Autism** involves differences in social communication plus focused interests, love of routine and often unusual sensory responses. The US CDC estimated about 1 in 31 eight year olds were identified in 2022, a rise driven largely by wider diagnosis. **ADHD** involves lasting patterns of inattention, impulsivity and restlessness. It affects about 5% of children worldwide and often continues into adulthood. Both are highly heritable, around 70 to 80% in twin studies.

Introversion is simply the low end of extraversion. Introverts are not necessarily shy. They tend to find social settings less rewarding and recharge alone. **Sensory processing sensitivity**, popularized by Elaine Aron as the "highly sensitive person", describes people who process input deeply and are easily overwhelmed. Estimates put it at 20 to 30% of people. Whether it is a separate trait or a mix of neuroticism and openness is **debated**.

Measurable signals

SIGNAL	WHAT IT REFLECTS	TOOL USED ON A LIVING PERSON
Big Five and HEXACO scores	Broad personality traits	BFI-2, NEO-PI-3, HEXACO-PI-R, ratings by friends
Temperament	Inborn reactivity in children	Infant Behavior Questionnaire, lab observation
Values	Life priorities	Portrait Values Questionnaire
Life story themes	Narrative identity	Life Story Interview, coded for redemption and agency
Sleep stages	Sleep quality and structure	Polysomnography, home EEG headbands
Daily rhythms	Chronotype and regularity	Munich Chronotype Questionnaire, wrist actigraphy, saliva melatonin
Stress load	Acute and chronic stress	Saliva or hair cortisol, heart rate variability
Inflammation	Immune state linked to mood	Blood CRP, IL-6
Gut microbes	Microbiome makeup	Stool sequencing
Fitness	Exercise capacity	VO2 max test, step counts
Cognitive aging	Speed, memory, knowledge	NIH Toolbox, standard neuropsychological tests

Key takeaways

- Personality is well described by five or six broad traits that predict real outcomes. Big Five versus HEXACO is debated, but both work.
- Traits are fairly stable in rank order, yet most people grow more conscientious, agreeable and calm with age.
- About 40 to 50% of trait variation links to genes. The non-shared environment matters more than the shared home.
- Identity adds goals, values and a life story to traits. Life stories form in adolescence.
- The brain overbuilds and then prunes. The prefrontal cortex matures late. Speed peaks early, knowledge peaks late, and emotional balance often improves in old age.
- Sleep, body clock, stress, exercise, hormones and inflammation shape mood daily. Gut brain findings in humans are still early.
- Autism, ADHD, introversion and sensitivity are common natural variations in how minds work.

SOURCES AND FURTHER READING

- Roberts, B. W., Walton, K. E., and Viechtbauer, W. (2006). Patterns of mean-level change in personality traits across the life course. *Psychological Bulletin*. https://doi.org/10.1037/0033-2909.132.1.1
- Ashton, M. C., and Lee, K. (2007). Empirical, theoretical, and practical advantages of the HEXACO model of personality structure. *Personality and Social Psychology Review*. https://doi.org/10.1177/1088868306294907
- Polderman, T. J. C., et al. (2015). Meta-analysis of the heritability of human traits based on fifty years of twin studies. *Nature Genetics*. https://doi.org/10.1038/ng.3285
- Hartshorne, J. K., and Germine, L. T. (2015). When does cognitive functioning peak? *Psychological Science*. https://doi.org/10.1177/0956797614567339
- Bethlehem, R. A. I., et al. (2022). Brain charts for the human lifespan. *Nature*. https://doi.org/10.1038/s41586-022-04554-y
- McEwen, B. S. (1998). Protective and damaging effects of stress mediators. *New England Journal of Medicine*. https://doi.org/10.1056/NEJM199801153380307
- Cryan, J. F., et al. (2019). The microbiota-gut-brain axis. *Physiological Reviews*. https://doi.org/10.1152/physrev.00018.2018
- Dantzer, R., et al. (2008). From inflammation to sickness and depression: when the immune system subjugates the brain. *Nature Reviews Neuroscience*. https://doi.org/10.1038/nrn2297

CHAPTER 12

What Makes Us Human, and What Is Still Unknown

This closing chapter pulls the report together. First it asks what is truly special about humans and what we share with other animals. The honest answer is that most of our parts are shared, but a few abilities combine in us to make something new: culture that builds on itself across generations. Then it lays out a full "specification of a person", a checklist of every layer that makes one human that particular human, with how scientists measure each layer today. Then it names the biggest open questions, where nobody yet knows the answer. It ends with a short reflection and a reading list for the whole report.

Shared with other animals

Almost every part of the human toolkit has roots in other species. This matters because it shows that the human mind is an extension of the animal mind, not a separate thing.

- **Emotions.** All mammals share core circuits for fear, rage, seeking, care for young, play and panic at separation. Jaak Panksepp mapped these in rats, which even make high pitched "laughing" calls when tickled. Whether animals *feel* these states as we do is unknown, but the brain machinery is clearly shared.
- **Tool use.** New Caledonian crows bend and cut leaves and twigs into hooked tools to fish out grubs. Chimpanzees use stones to crack nuts and sticks to fish termites. Some sea otters use rocks as anvils.
- **Culture in a simple sense.** Different chimp groups have different tool traditions. Humpback whale songs spread from population to population. Japanese macaques learned to wash sweet potatoes, and the habit spread through the troop.
- **Social smarts.** Chimps track who knows what. In a famous setup, a lower ranking chimp went for food that a dominant chimp could not see. Many primates console victims after fights. Dogs follow human pointing better than chimps do.
- **Memory and planning.** Scrub jays hide food and later recover it based on what, where and when they hid it. They re-hide food if another bird watched them. Some great apes save a tool for use the next day.

Unique, or uniquely combined

So what is different? Most researchers now say the difference is one of degree and combination rather than a single magic ingredient. Several capacities stand out.

Cumulative culture. Animals have traditions, but they rarely build on them. Humans add improvement after improvement over generations. Michael Tomasello calls this the **ratchet effect**: each step is kept so the next one can start higher. No single person could invent a smartphone, a kayak or even a good bow from scratch. Joseph Henrich's book *The Secret of Our Success* tells of European explorers who starved in places where local people thrived, because survival depended on inherited know-how, not raw intelligence.

Shared intentionality. Tomasello argues that the deep root is the ability to form shared goals and shared attention with others. A 1 year old points just to share interest in a dog with an adult. Apes point mainly to request things. Toddlers spontaneously help adults who drop something. They also expect partners to keep commitments in joint games. From shared intentionality come teaching, norms, institutions and morality.

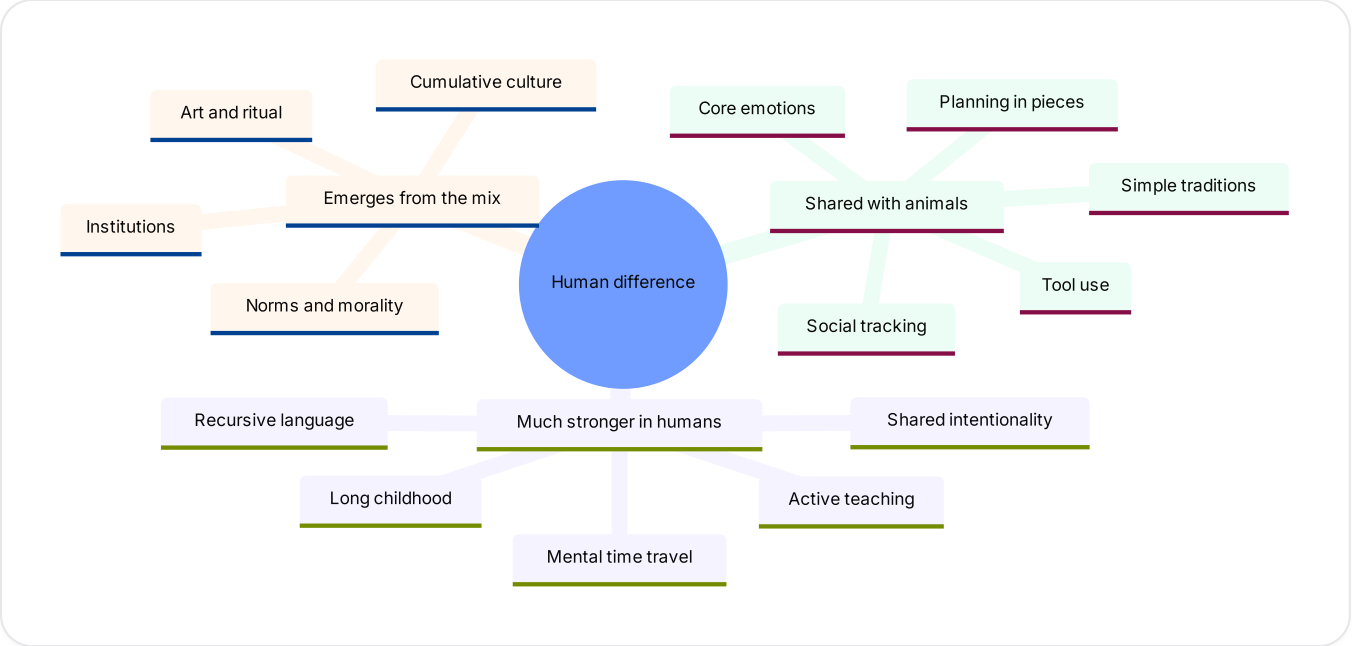
Recursive language. Many animals communicate. Only humans build unlimited new meanings by nesting phrases inside phrases. "The dog that chased the cat that ate the bird" is recursion. Language lets us talk about the past, the future, the absent and the imaginary, and transmit culture fast. Chapter 9 covers this in depth.

Mental time travel. Humans vividly relive the past and imagine detailed futures, then plan around them. Thomas Suddendorf and Michael Corballis argue that this flexible "mental time travel" is far more developed in humans, although scrub jays and apes show pieces of it. How far animals go is **debated**.

Teaching. True teaching, where an expert changes behavior at a cost to help a learner, is rare in animals. Meerkats bring pups disabled scorpions, and some ants lead others to food. In humans teaching is everywhere and is aided by a special readiness in children to accept what adults show them on purpose.

Long childhood. Human children depend on adults for well over a decade, much longer than any ape. This long apprenticeship gives time to absorb a huge cultural load. It also needs help from fathers, grandmothers and others, which Sarah Hrdy calls **cooperative breeding**.

Morality, art and ritual. Humans make rules about what is right, enforce them on third parties and feel guilt and shame about breaking them. People paint, carve, sing and hold rituals that serve no obvious survival need. Ochre engravings at Blombos Cave in South Africa date to about 75,000 to 100,000 years ago. Cave hand stencils in Indonesia have been dated to over 40,000 years ago.



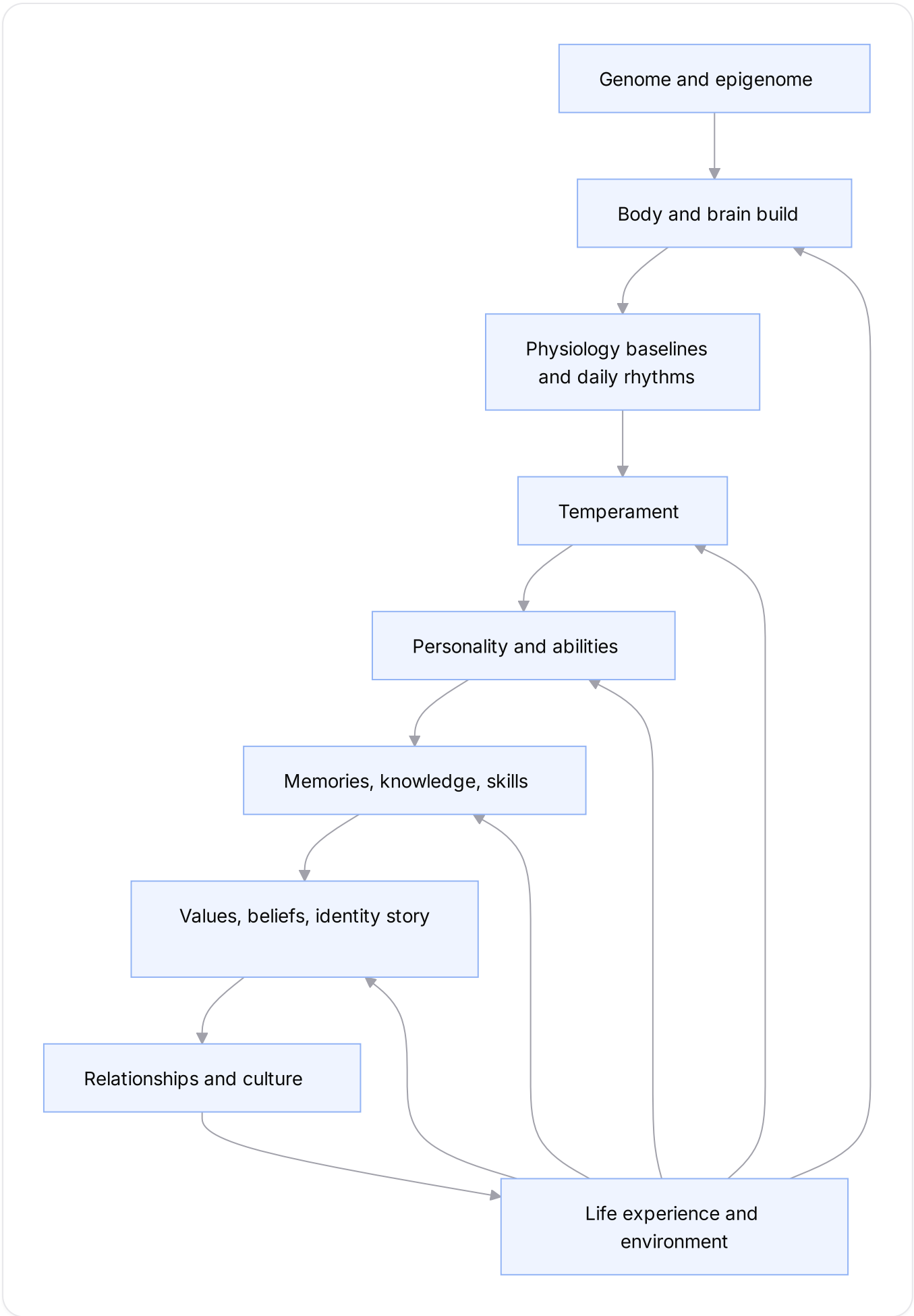
The specification of a person

If the earlier chapters describe the parts, this section asks how to describe one specific human in full. Each layer below is part of what makes your friend recognizably themselves. For each layer the table lists how science describes or measures it today. Many layers are measured only crudely, and some may never be captured completely.

LAYER	WHAT IT INCLUDES	HOW SCIENTISTS MEASURE OR DESCRIBE IT TODAY	HOW WELL CAPTURED TODAY
Genome	DNA sequence, about 3 billion letter pairs, plus variants	Whole genome sequencing; polygenic scores	Sequence well; meaning of variants poorly
Epigenome	Chemical marks that turn genes up or down	DNA methylation arrays, "epigenetic clocks"	Partial
Body build	Height, weight, shape, organs	Anthropometry, DEXA scans, MRI	Well
Brain structure and wiring	Size of regions, connections	Structural MRI, diffusion MRI connectomes	Coarse; synapse level unknown in living people
Physiology baselines	Resting heart rate, blood pressure, hormones, metabolism	Wearables, blood panels, ECG	Well over time
Senses	Acuity of sight, hearing, smell, taste, touch, pain threshold	Eye charts, audiograms, smell tests, quantitative sensory testing	Fairly well
Temperament	Inborn reactivity and self control	Parent reports, lab observation in childhood	Moderate
Personality	Traits like the Big Five and HEXACO	Questionnaires, ratings by others, behavior logs	Moderate to good
Cognitive abilities	Speed, memory span, reasoning, knowledge	IQ batteries, NIH Toolbox	Good for averages, misses context

LAYER	WHAT IT INCLUDES	HOW SCIENTISTS MEASURE OR DESCRIBE IT TODAY	HOW WELL CAPTURED TODAY
Autobiographical memories	Life events and how they are recalled	Autobiographical Memory Interview, diaries, life story interviews	Very partial; memory is reconstructed
Knowledge	Facts, beliefs, mental models of the world	Tests, interviews, written records	Partial
Skills	Motor skills, crafts, language fluency, expertise	Performance tests, motion capture	Partial
Values and beliefs	What matters most, moral and political views	Schwartz values survey, Moral Foundations Questionnaire	Moderate
Narrative identity	The life story the person tells	Coded life story interviews	Partial
Relationships	Who they love, trust, depend on, avoid	Network maps, attachment measures	Partial
Habits and routines	Daily patterns of action	Experience sampling, phone and wearable logs	Good for behavior, weak for reasons
Voice	Pitch, timbre, accent, rhythm, word choice	Acoustic analysis, language samples	Good
Face and expression	Face shape, typical expressions	3D face scans, Facial Action Coding System	Good
Movement style	Gait, posture, gestures	Motion capture, gait analysis	Good

LAYER	WHAT IT INCLUDES	HOW SCIENTISTS MEASURE OR DESCRIBE IT TODAY	HOW WELL CAPTURED TODAY
Emotional patterns	What triggers which feelings, how fast they pass	Experience sampling, heart rate variability, EMA mood diaries	Moderate
Daily rhythms	Chronotype, sleep, energy across the day	Actigraphy, sleep diaries, melatonin timing	Good
Health state	Illnesses, inflammation, microbiome	Medical records, blood tests, stool sequencing	Good for snapshots
Culture and language	Native tongue, norms, humor, religion, taste	Ethnography, surveys, language samples	Descriptive only
Inner experience	What it feels like to be them	Self report, phenomenology interviews	Not directly measurable


Genome and epigenome
Body and brain build
Physiology baselines and daily rhythms
Temperament
Personality and abilities
Memories, knowledge, skills
Values, beliefs, identity story
Relationships and culture
Life experience and environment

Two lessons stand out from the table. First, the layers are not independent. Genes shape temperament, temperament shapes the friends you choose, and friends reshape your values and even your stress hormones. Second, the layers that feel most like "you", such as memories, values and inner experience, are the ones science captures least.

The biggest open questions

The hard problem of consciousness. Science can link brain activity to reports of experience, such as seeing red or feeling pain. But why does any physical process feel like something from the inside? David Chalmers named this the "hard problem" in 1995. Leading theories, such as global workspace theory and integrated information theory, disagree sharply. A large "adversarial collaboration" that pitted two theories against each other, published from 2023 onward, did not cleanly confirm either. No one knows how to test consciousness in a person who cannot report.

The memory code. Researchers can now find and even switch on **engrams**, the sets of neurons that hold a specific memory, in mice. But we do not know how a rich memory, like your tenth birthday, is written in the strength and pattern of synapses. Nor do we know how it is changed every time it is recalled.

The binding problem. Color, shape, motion and sound are processed in different brain areas. Yet we see one red ball bouncing with one thud. How the brain binds these into a single scene is still unsettled.

Why we sleep. Sleep is found in nearly every animal studied, even jellyfish. Ideas include memory consolidation, brain waste clearance, energy saving and synapse resetting. Each has support. Why sleep is needed so badly that total loss can kill is not fully known.

Free will. Brain activity related to a simple movement can begin before people report deciding to move, as shown in Benjamin Libet's 1980s studies. Many took this as proof that free will is an illusion. Later work suggests that early signal may partly reflect random background noise reaching a threshold. Philosophers still debate whether free will needs to be free of causes at all.

What emotions are. Are there a few built-in "basic emotions" with fixed body signatures, as Paul Ekman argued? Or does the brain construct emotions from body signals plus learned concepts, as Lisa Feldman Barrett argues? The evidence is still **contested** (see Chapter 7).

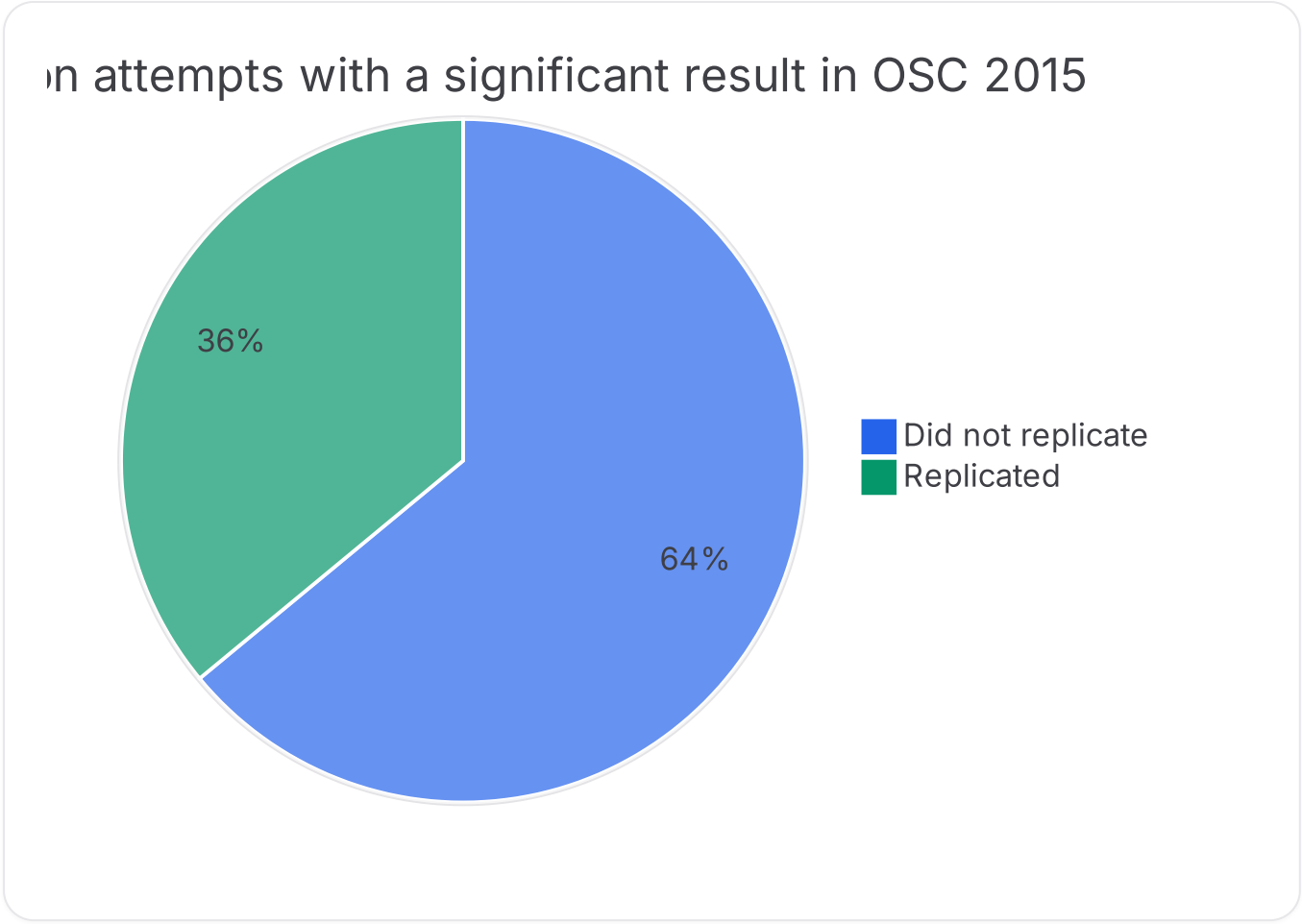
What makes each person unique. Identical twins raised together differ in personality, interests and disease. We do not yet know how much of that comes from random noise in brain development, tiny life differences or effects we cannot see yet. In one striking

experiment, genetically identical mice raised in the same large enclosure came to explore it in very different ways, and their hippocampus grew new neurons at different rates to match. Small differences in early experience seem to snowball into individuality.

How the levels connect. We can describe molecules, cells, circuits, behavior and culture. We cannot yet explain how they link. Why a given pattern of brain activity amounts to a specific thought, or how a cultural rule changes a stress hormone, is mostly unmapped. Most findings in this report live at one level and are only loosely tied to the others.

What a self is. Chapter 4 showed that the sense of self can be altered by brain injury, drugs, meditation and illness. Philosophers still debate whether a self is a thing, a process or a useful story. Related puzzles remain open too. If your memories, body cells and personality all slowly change, what makes you the same person you were at age five? Psychology suggests people answer this mostly through continuity of moral character and memory, but this describes our intuitions, not the underlying fact.

The replication crisis. In 2015 the Open Science Collaboration repeated 100 published psychology studies. Only about 36% produced a statistically significant result again, and effects were on average about half as large. Ego depletion, power posing and some priming effects largely failed to replicate. The field has since adopted preregistration, larger samples and shared data. Readers of this report should treat single striking studies with caution. This report has tried to flag such cases.



Measurable signals

SIGNAL	WHAT IT REFLECTS	TOOL
Joint attention and pointing	Shared intentionality in infants	Lab observation, eye tracking
Over-imitation	Cultural learning readiness	Imitation tasks with puzzle boxes
Episodic future thinking	Mental time travel	Autobiographical interview tasks
Perturbational complexity index	Level of consciousness in unresponsive people	TMS combined with EEG
Replicability of a finding	Trust in a psych effect	Multi-lab replication projects

Closing reflection

Across these twelve chapters a picture emerges. A person is not a soul sitting in a machine. Nor is a person only a machine. A person is a living body that predicts and regulates itself. It is wrapped in feeling, shaped by memory and steered by values. It is tuned at every level by other people. The heart rate of a partner, the words of a parent and the tools of a hundred dead generations all live inside one human life.

This is why describing a single human is so hard. The parts we measure best, like genome, face and gait, are the least personal. The parts that matter most to the people who love someone, like their humor, their way of comforting and their particular memories, are spread across brain, body and relationships. Much of that is invisible to today's tools. Science has learned a vast amount. It is also honest that the deepest questions are still open. Holding both facts at once is the right starting point for anyone who wants to understand a human being.

SOURCES AND FURTHER READING

- Tomasello, M., Carpenter, M., Call, J., Behne, T., and Moll, H. (2005). Understanding and sharing intentions: the origins of cultural cognition. *Behavioral and Brain Sciences*. https://doi.org/10.1017/S0140525X05000129
- Suddendorf, T., and Corballis, M. C. (2007). The evolution of foresight: what is mental time travel, and is it unique to humans? *Behavioral and Brain Sciences*. https://doi.org/10.1017/S0140525X07001975
- Hunt, G. R. (1996). Manufacture and use of hook-tools by New Caledonian crows. *Nature*. https://doi.org/10.1038/379249a0
- Open Science Collaboration (2015). Estimating the reproducibility of psychological science. *Science*. https://doi.org/10.1126/science.aac4716
- Josselyn, S. A., and Tonegawa, S. (2020). Memory engrams: recalling the past and imagining the future. *Science*. https://doi.org/10.1126/science.aaw4325
- Chalmers, D. J. (1995). Facing up to the problem of consciousness. *Journal of Consciousness Studies*. https://consc.net/papers/facing.html
- Stanford Encyclopedia of Philosophy. Consciousness. https://plato.stanford.edu/entries/consciousness/

Further reading for the whole report

Books

TITLE	AUTHOR	WHY READ IT	CHAPTERS
Behave	Robert Sapolsky	Explains one behavior from seconds to millions of years before it	2, 7, 8, 10
Principles of Neural Science	Kandel and colleagues	The standard textbook of neuroscience	1, 2, 3, 5
How Emotions Are Made	Lisa Feldman Barrett	The case for constructed emotion	7, 12
Descartes' Error	Antonio Damasio	Why emotion and body are part of reason	7, 8
Being You	Anil Seth	Consciousness and self as prediction	3, 4, 12
The Seven Sins of Memory	Daniel Schacter	How and why memory fails	5
Thinking, Fast and Slow	Daniel Kahneman	Biases and two modes of thought; some cited priming studies failed to replicate	8
Why We Sleep	Matthew Walker	Readable sleep science; some claims have been criticized as overstated	11
The Secret of Our Success	Joseph Henrich	Culture as the engine of human evolution	10, 12
Becoming Human	Michael Tomasello	How shared intentionality develops in children	10, 12
Grooming, Gossip and the Evolution of Language	Robin Dunbar	The social brain and why we talk	9, 10
Attached	Amir Levine and Rachel Heller	Adult attachment for general readers	10

TITLE	AUTHOR	WHY READ IT	CHAPTERS
Personality	Daniel Nettle	Short clear guide to the Big Five	11
The Language Instinct	Steven Pinker	Classic case for language as a human instinct	9
Why Zebras Don't Get Ulcers	Robert Sapolsky	Stress and the body	7, 11
The Body Keeps the Score	Bessel van der Kolk	Trauma and the body; influential but some claims debated	7, 11

Websites and courses

RESOURCE	WHAT IT OFFERS	LINK
Stanford Encyclopedia of Philosophy	Free expert essays on mind, consciousness, free will	https://plato.stanford.edu/
BrainFacts.org	Neuroscience basics from the Society for Neuroscience	https://www.brainfacts.org/
The Transmitter	News and analysis on neuroscience research	https://www.thetransmitter.org/
MIT OpenCourseWare 9.13 The Human Brain	Full lecture course by Nancy Kanwisher	https://ocw.mit.edu/courses/9-13-the-human-brain-spring-2019/
Noba Project	Free peer reviewed psychology textbook chapters	https://nobaproject.com/
Center for Open Science	Replication projects and open research tools	https://www.cos.io/