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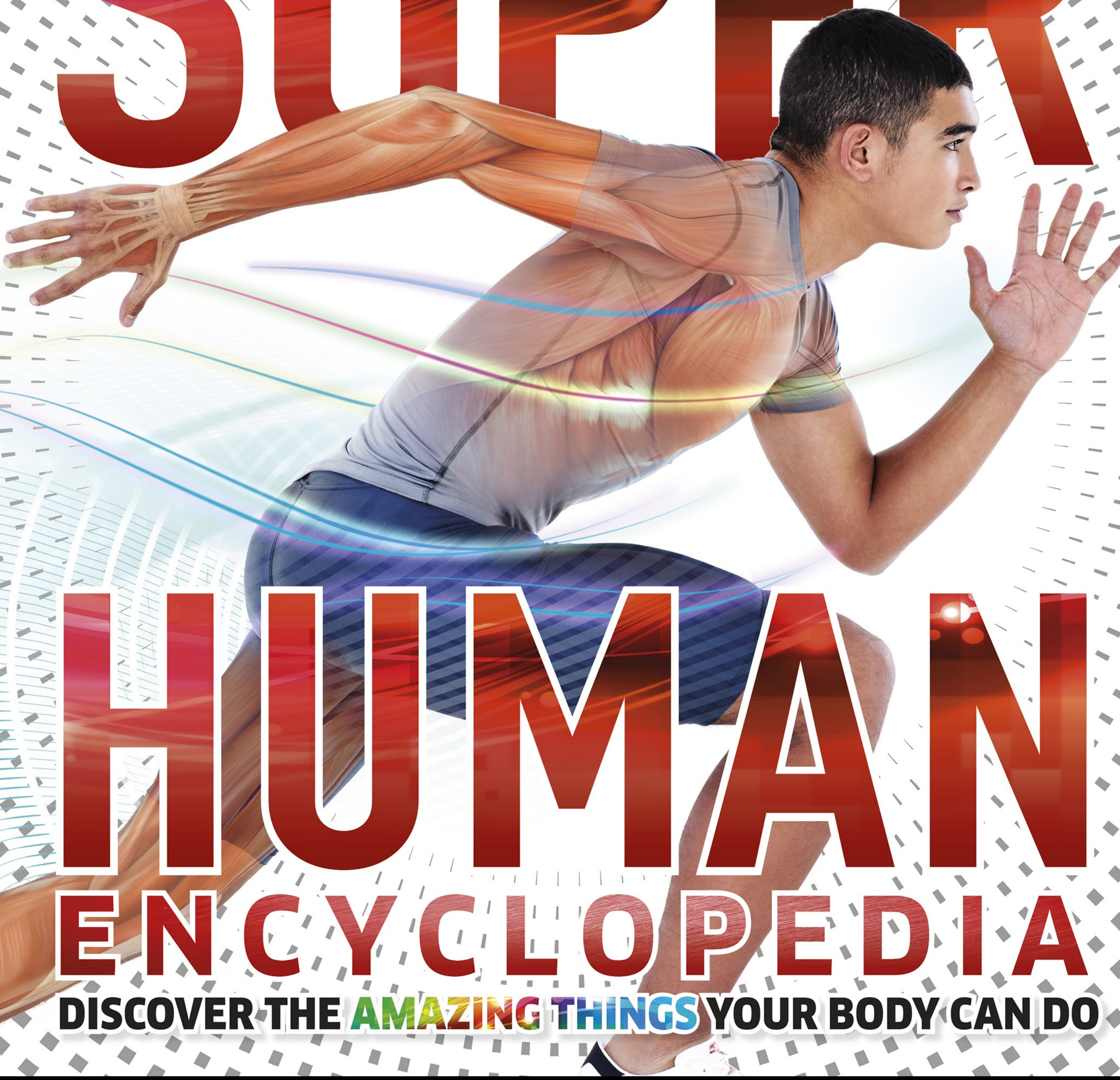
SUPER HUMAN ENCYCLOPEDIA



DISCOVER THE AMAZING THINGS YOUR BODY CAN DO

SUPER HUMAN ENCYCLOPEDIA

DISCOVER THE AMAZING THINGS YOUR BODY CAN DO

Steve Parker

Chief editorial consultant
Professor Robert Winston

DK

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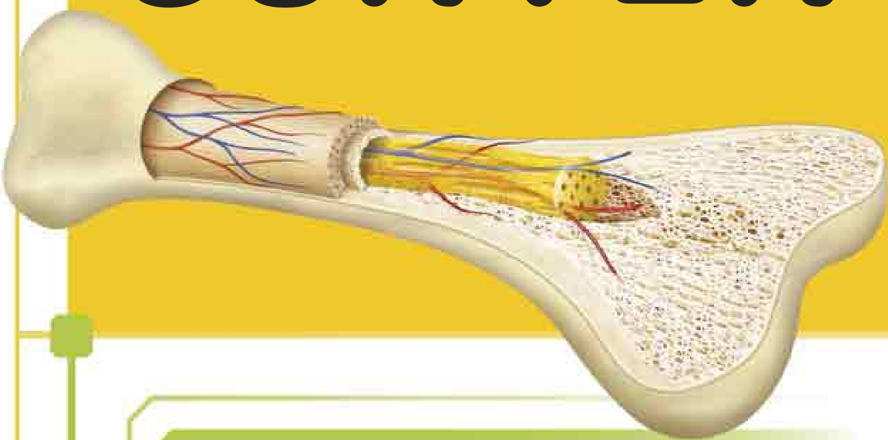

BODY FRAMEWORK

MISSION CONTROL

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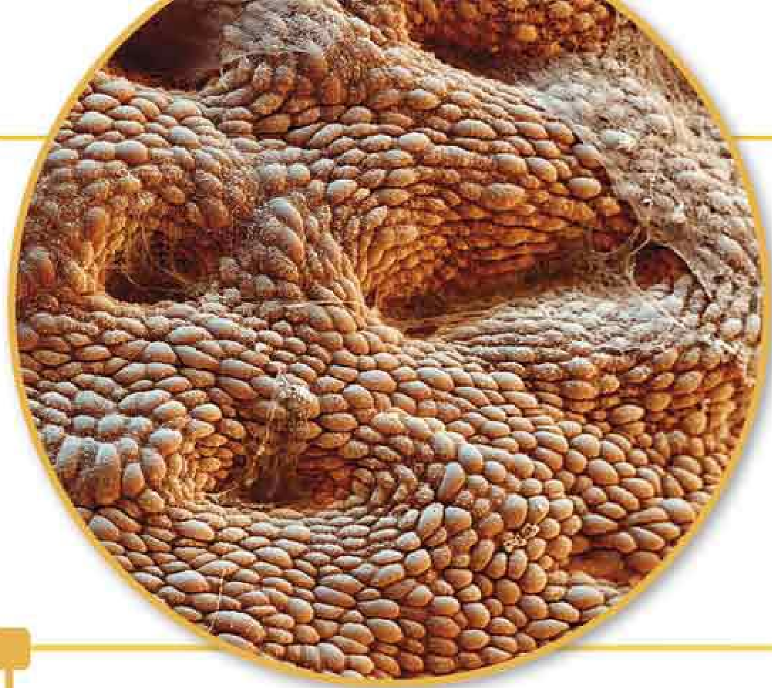

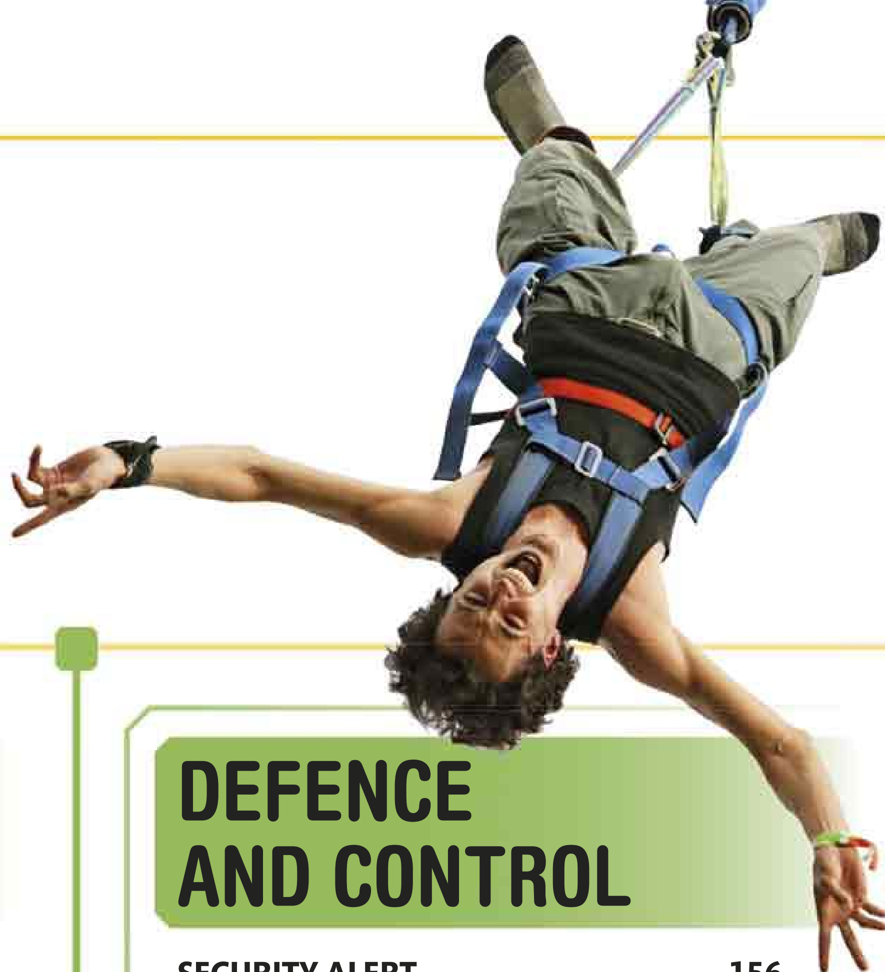

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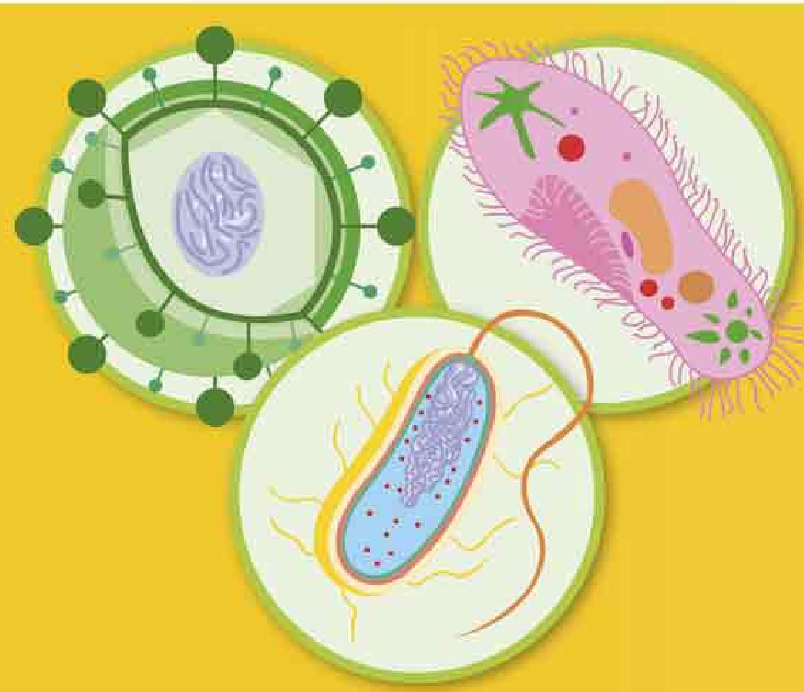
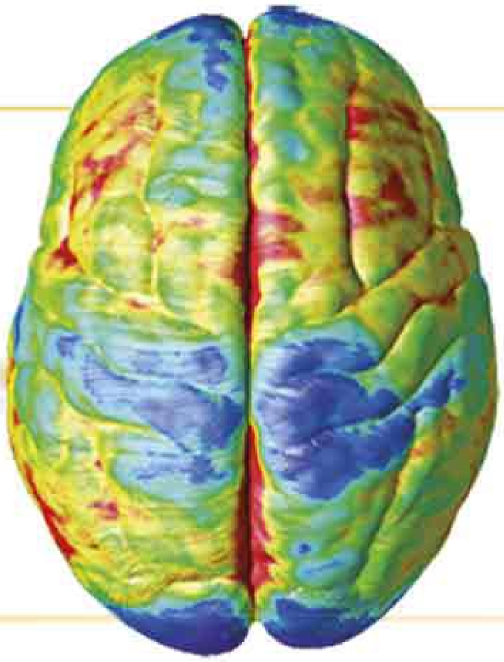
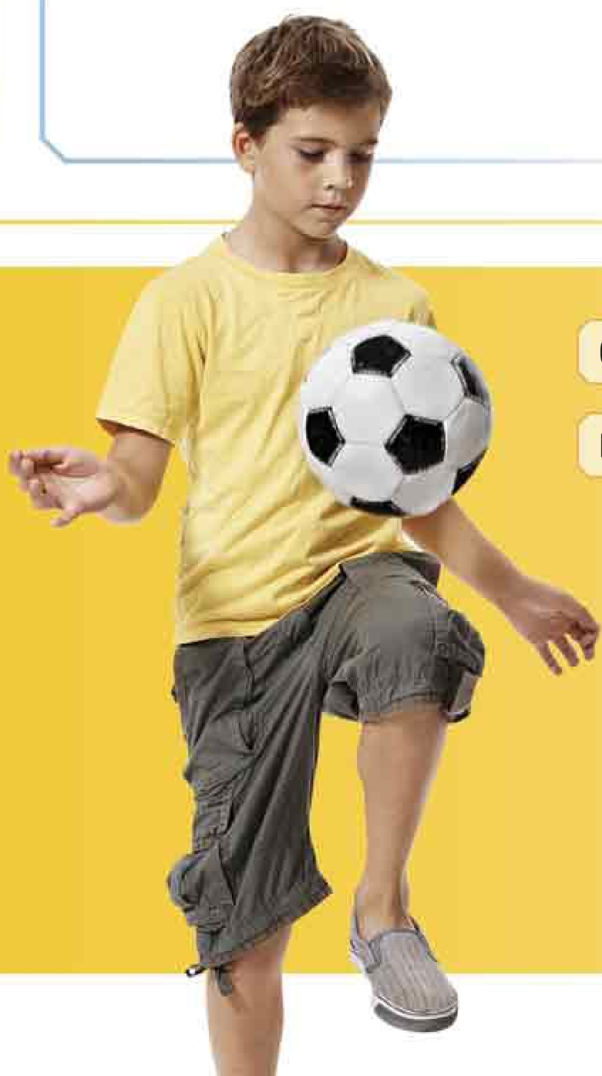
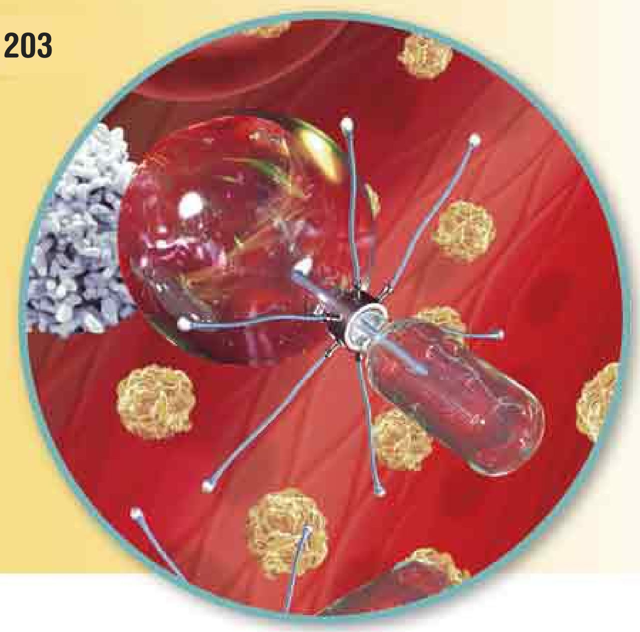




NEW LIFE AND GROWTH

FUTURE HUMANS





HUMAN PLANET

Where we live

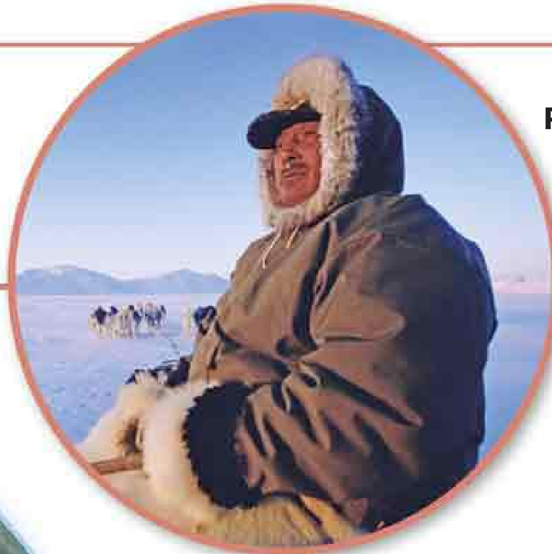
Humans have adapted to almost every corner of planet Earth. From the coldest poles and steepest mountains to sweltering rainforests and scorching deserts, people survive and thrive. Of course, this is due partly to our cleverness and skill in making suitable clothing, suits, shelters, warming fires, cooling fans, and other inventions. But over thousands of years, the body itself has also adapted to enormously varied environments.

RAINFORESTS

People living in tropical forests tend to have a smallish, slim stature, and wear little clothing. They have keen senses and the ability to remember forest tracks, plant uses, and signs of animals.

SPACE

Sealed in a spacesuit, with a supply of air to breathe, humans can even venture out into space. The suit also has temperature control, so it does not fry in the sun's glare or freeze in the shadows.

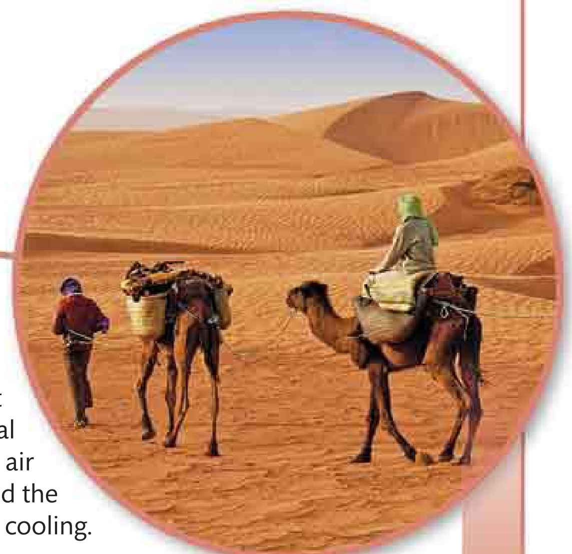


POLAR REGIONS

People with a broad physique tend to lose heat less quickly in cold conditions, especially when clothed in thick furs and skins of local animals that have also adapted to the snowy landscape.

MOUNTAINS

A broad chest, large lungs, and relatively more red blood cells allow mountain people to take in maximum oxygen from the thin air at altitude.



DESERTS

A slim body loses warmth more rapidly in hot conditions. Traditional loose robes allow air to circulate around the body for added cooling.

UNDER WATER

Divers can stay under water for hours, with the help of a scuba tank containing compressed air. This air is breathed in through a regulator that maintains air pressure at a safe level and supplies air as necessary.

ALL SHAPES AND SIZES

The same but different

There are so many human bodies in the world that counting them all would take more than 200 years! They all have the same main parts, such as skin, a heart, bones, and a brain. Yet they are all different. Each body is an individual person, outside and in. You have your own facial appearance, eye colour, and hair style, and your own likes, dislikes, and memories. It is this endless variety that makes the human body truly fascinating.

“250 babies are born every minute”

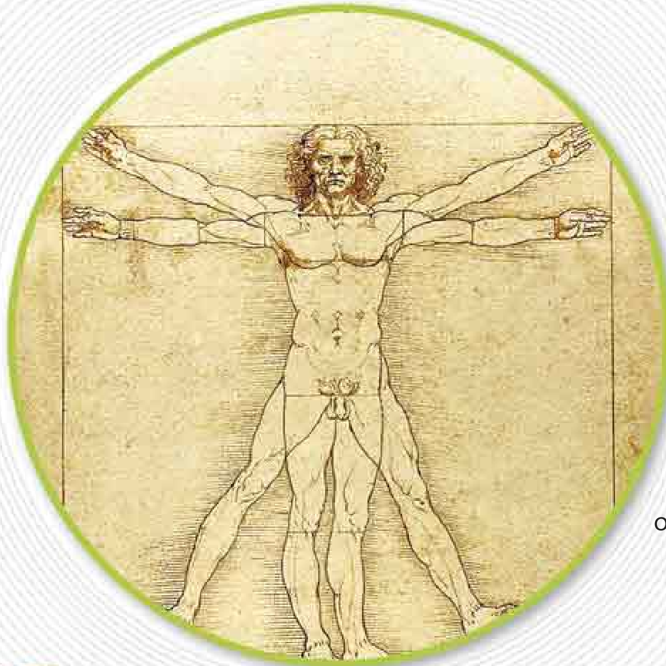
All smiles

All these people are different in skin colour, hair style, eye shape, cheek width, and many other features. Yet they all have something in common – they are smiling. Facial expressions such as anger, surprise, and pleasure are understood throughout most of the world.

ALMOST IDENTICAL

Identical twins look similar, especially when they are babies. But each develops small physical variations, from fingerprints to nose length and the shape of their smiles. As they grow up together, their characters become more individual too, with different favourite foods, fashions, and friends.

THE YEAR THE MOST HUMANS WERE BORN – 1963

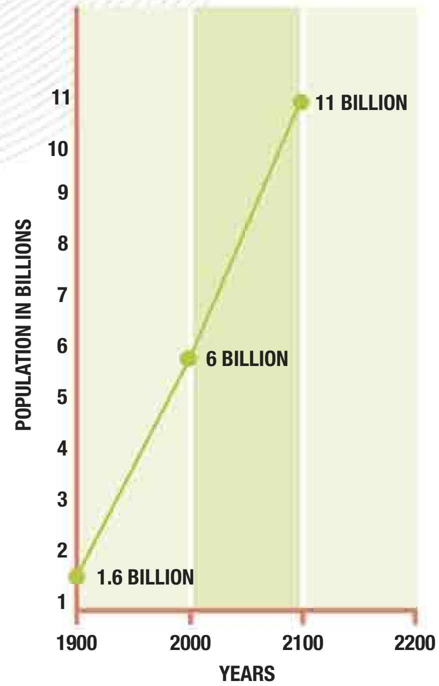


COMMON PROPORTIONS

The structure of the human body has been studied for thousands of years. This sketch, by Italian artist and anatomist Leonardo da Vinci, was drawn around 1490. On average, in relation to total height, the legs are one-half, the arms just over two-fifths, and the head one-eighth.

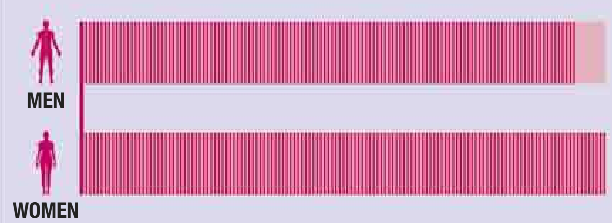
RAPID GROWTH

There are more people on Earth now than have ever lived in all the centuries before. For thousands of years humans numbered in the low millions, rising slowly to a billion by the 1800s. Since then it has grown rapidly to more than 7 billion today and is expected to reach 11 billion by the end of this century.



STATS AND FACTS

AVERAGE LIFESPAN



65 years

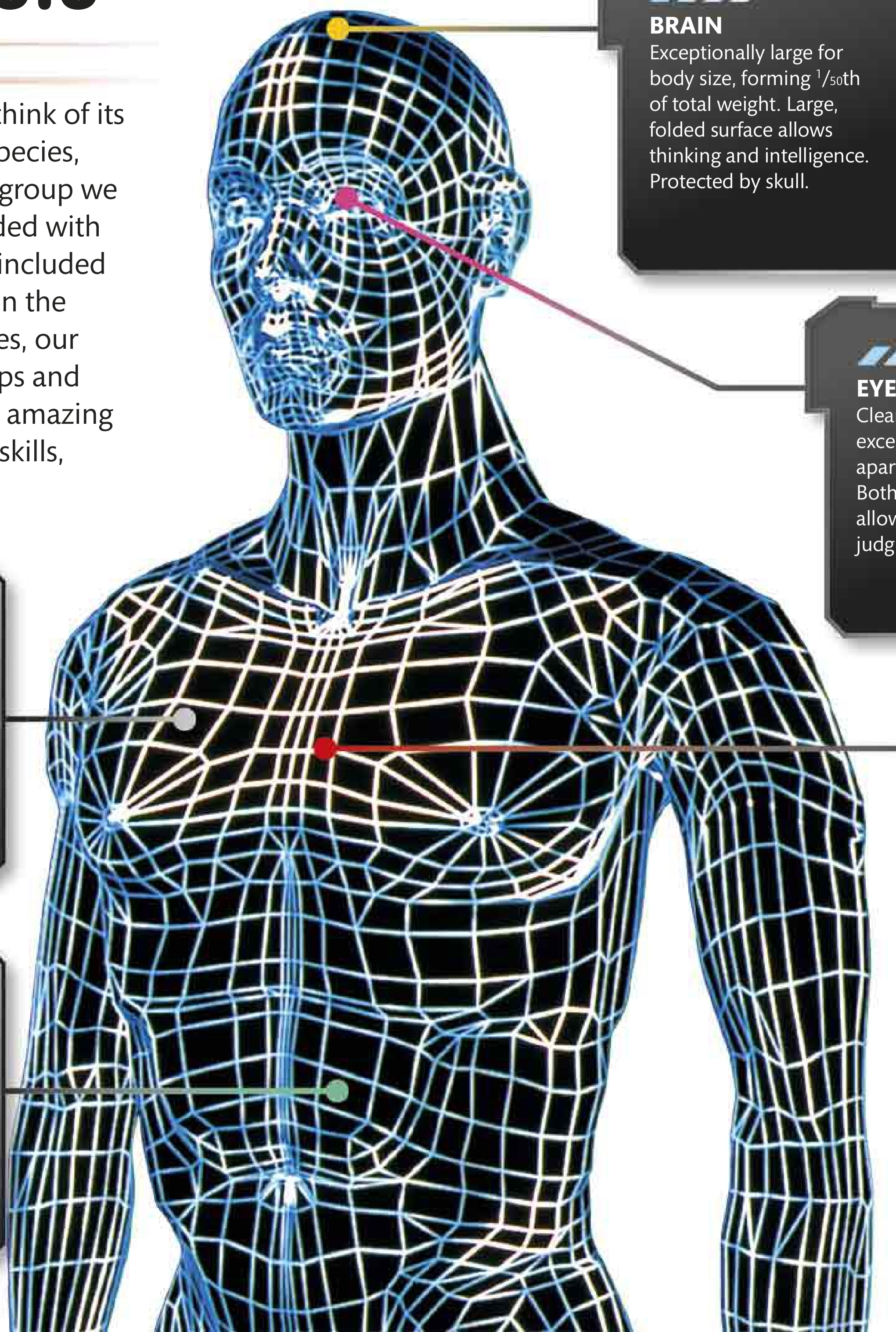
69 years

270 MILLION TONNES (300 MILLION TONS) The total weight of all humans on Earth = **800 ×** Empire State Building

WHAT IS A HUMAN?

Body analysis

What would alien visitors to Earth think of its main large inhabitants? The human species, *Homo sapiens*, belongs to the animal group we call mammals, which are warm-blooded with hair or fur. Among mammals, we are included with the lemurs, monkeys, and apes, in the group called primates. Within primates, our closest cousins are apes such as chimps and gorillas. But with our upright posture, amazing intelligence, and incredible language skills, we are unique.



BRAIN
Exceptionally large for body size, forming 1/50th of total weight. Large, folded surface allows thinking and intelligence. Protected by skull.

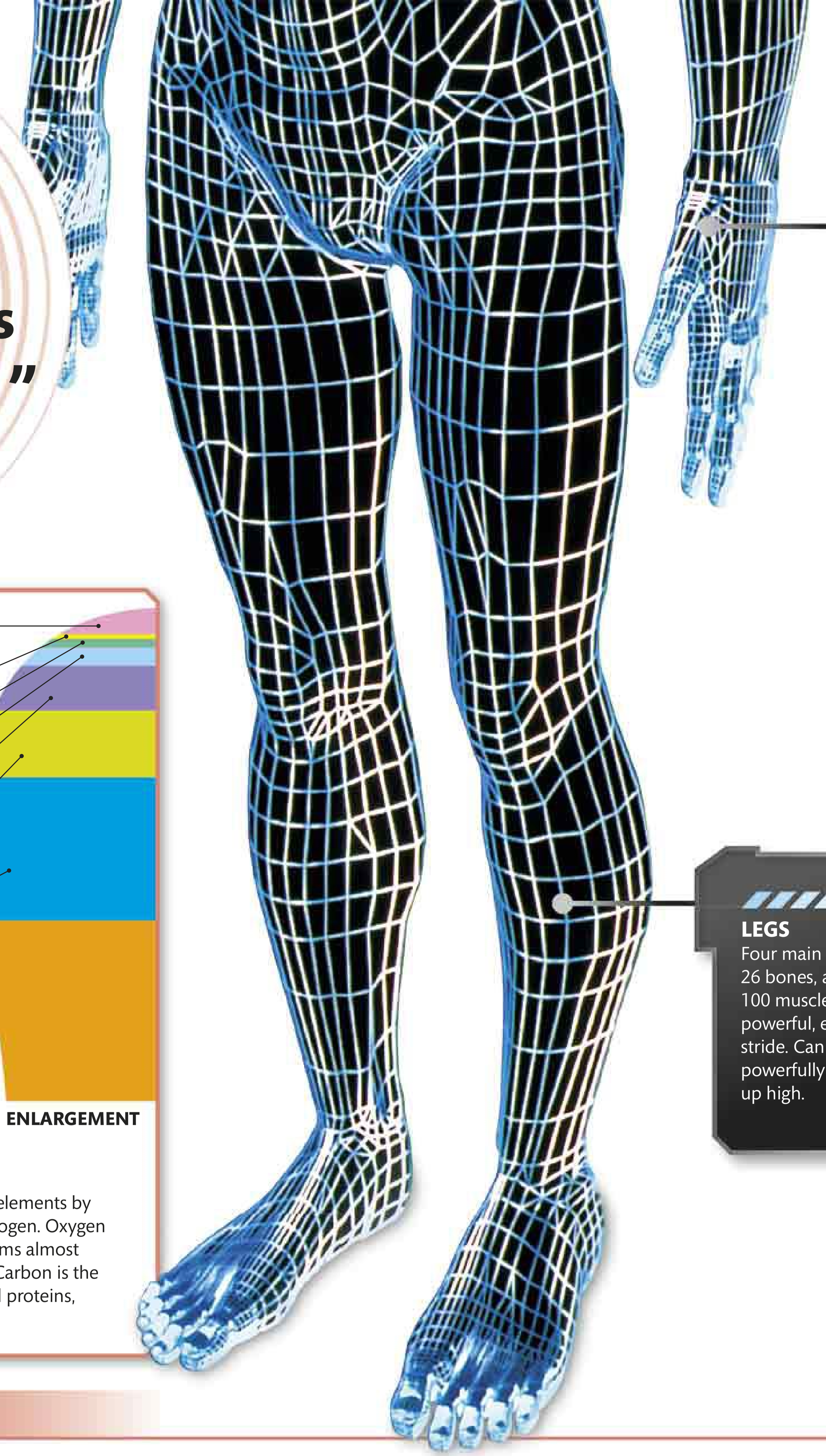
EYES
Clear sharp vision, with excellent ability to tell apart myriad colours. Both eyes look forwards, allowing very accurate judging of distances.

LUNGS
Able to take in oxygen in a wide range of conditions and air qualities. Can withstand stretch-squeeze by breathing muscles 25,000 times daily.

HEART
Specialized muscle bag that pumps billions of times during life. Precise control to slow down at rest and speed many times faster for activity.

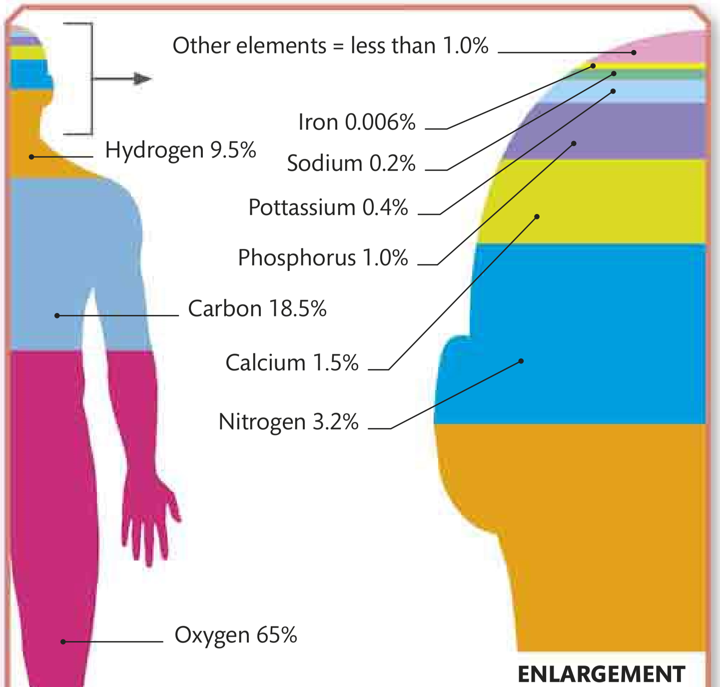
DIGESTIVE SYSTEM
Generalized to cope with many kinds of food, known as an omnivorous diet. Enamel covering of teeth is an exceptionally hard-wearing material.

“Our scientific name *Homo sapiens* means ‘wise human’ ”



HANDS
Over 30 muscles and 27 bones combine to make an amazing grab-like device that can punch hard and lift great weight, yet also pick up a pin.

LEGS
Four main sets of joints, 26 bones, and over 100 muscles give a long, powerful, energy-efficient stride. Can also kick powerfully and jump up high.



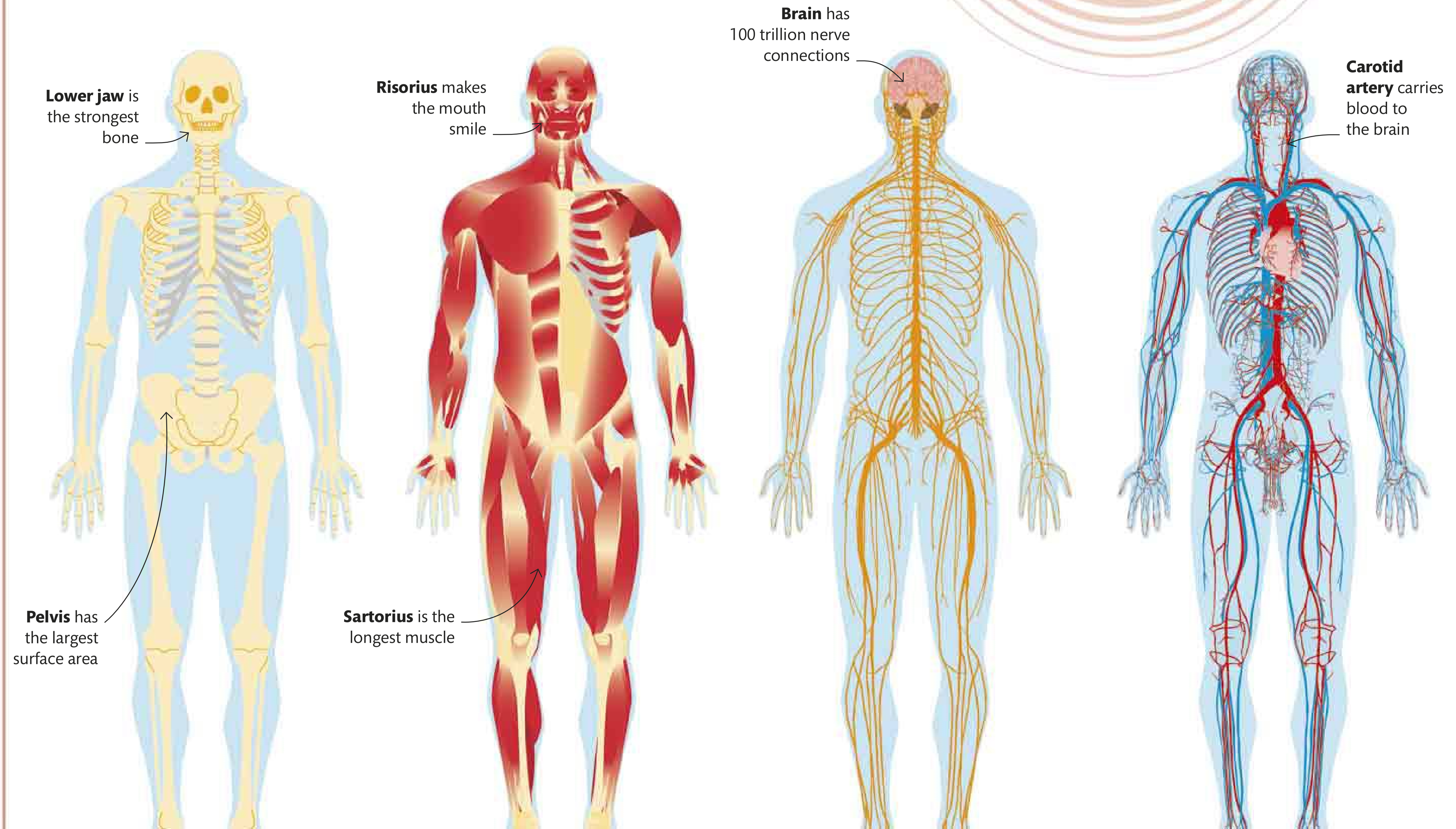
MAIN INGREDIENTS
The body’s most common chemical elements by weight are oxygen, carbon, and hydrogen. Oxygen and hydrogen make water, which forms almost two-thirds of a human’s body mass. Carbon is the basic building block, needed to build proteins, carbohydrates, and fats.

WORKING TOGETHER

Systems and organs

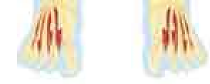
The body is a marvel of coordination – a massive team of more than 2,000 parts working together. The main parts, such as the liver, intestines, heart, lungs, and brain, are known as organs. Each organ, along with other smaller parts, is part of a larger system, which carries out a vital task to keep the body alive. All the systems rely on each other to work properly.

"Working together, body systems burn an average of 1,700 kcal a day for men"



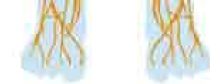
SKELETON

Bones form the skeletal system, to support and protect soft parts. Joints allow it to take up endless different positions, moved by the muscles.



MUSCLES

There are over 640 muscles. Attached to bones, each muscle causes movements by pulling the bone into a new position. Muscles are controlled by nerves.

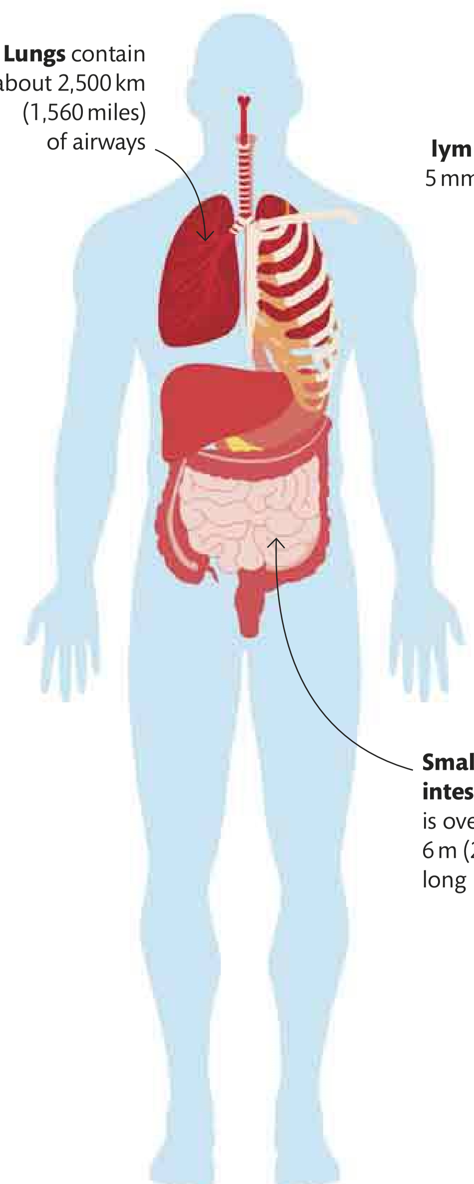


NERVES

Nerves carry signals from the brain, which also receives data from sense organs such as the eyes and ears. The nervous system is nourished by blood.

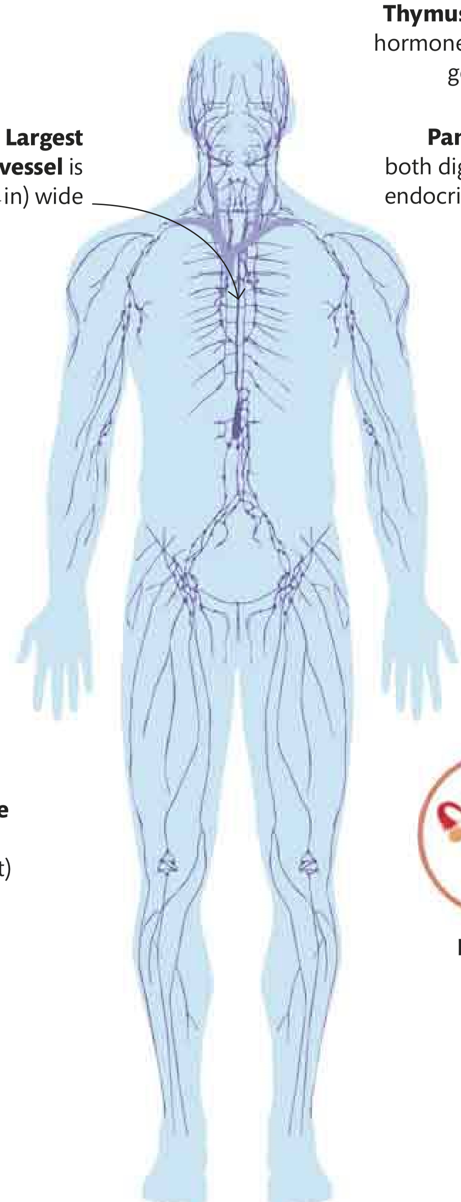
HEART AND BLOOD

The heart sends blood nonstop around our huge network of blood vessels. Blood carries oxygen from the lungs and nutrients from the digestive system.



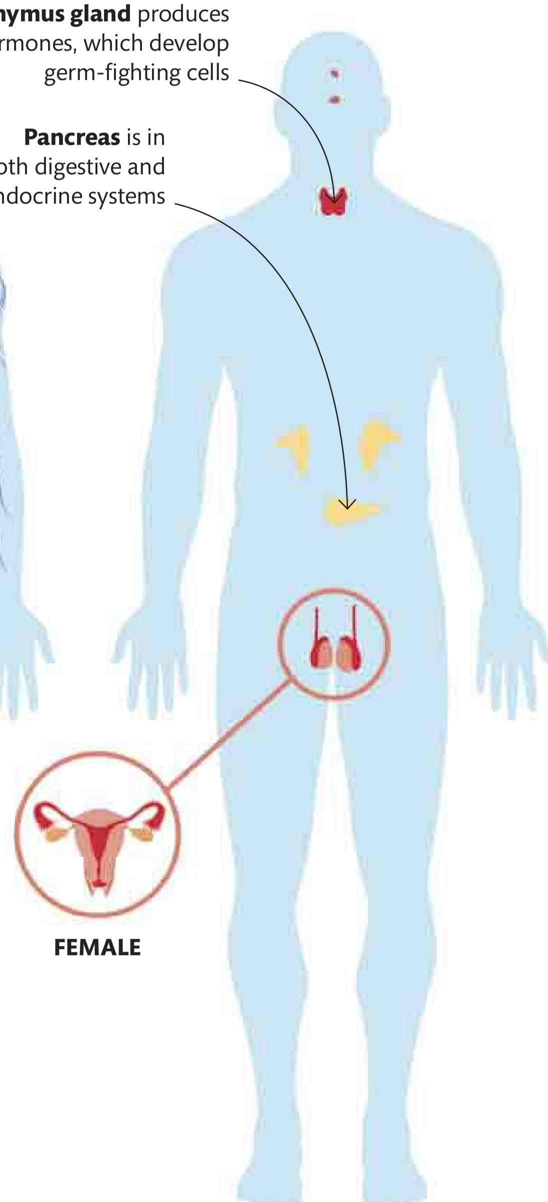
LUNGS AND DIGESTION

Lungs take oxygen from the air, while the stomach and intestines absorb nutrients from food. Both depend on the immune system for protection.



LYMPH AND IMMUNITY

The lymphatic system transports lymph around its web of vessels. It is also home to the micro-defenders of the immune system, which is under the control of hormones.



HORMONES

Glands of the endocrine system make many chemical messengers, or hormones. These control and coordinate other systems, such as skeletal growth.

FULL BODY SCAN

MR (magnetic resonance) scanners use magnets and radio waves to picture the body's insides. Except for air in the lungs and gas in the intestines, there are no gaps. Parts are pressed close together – as one moves, so do the others.

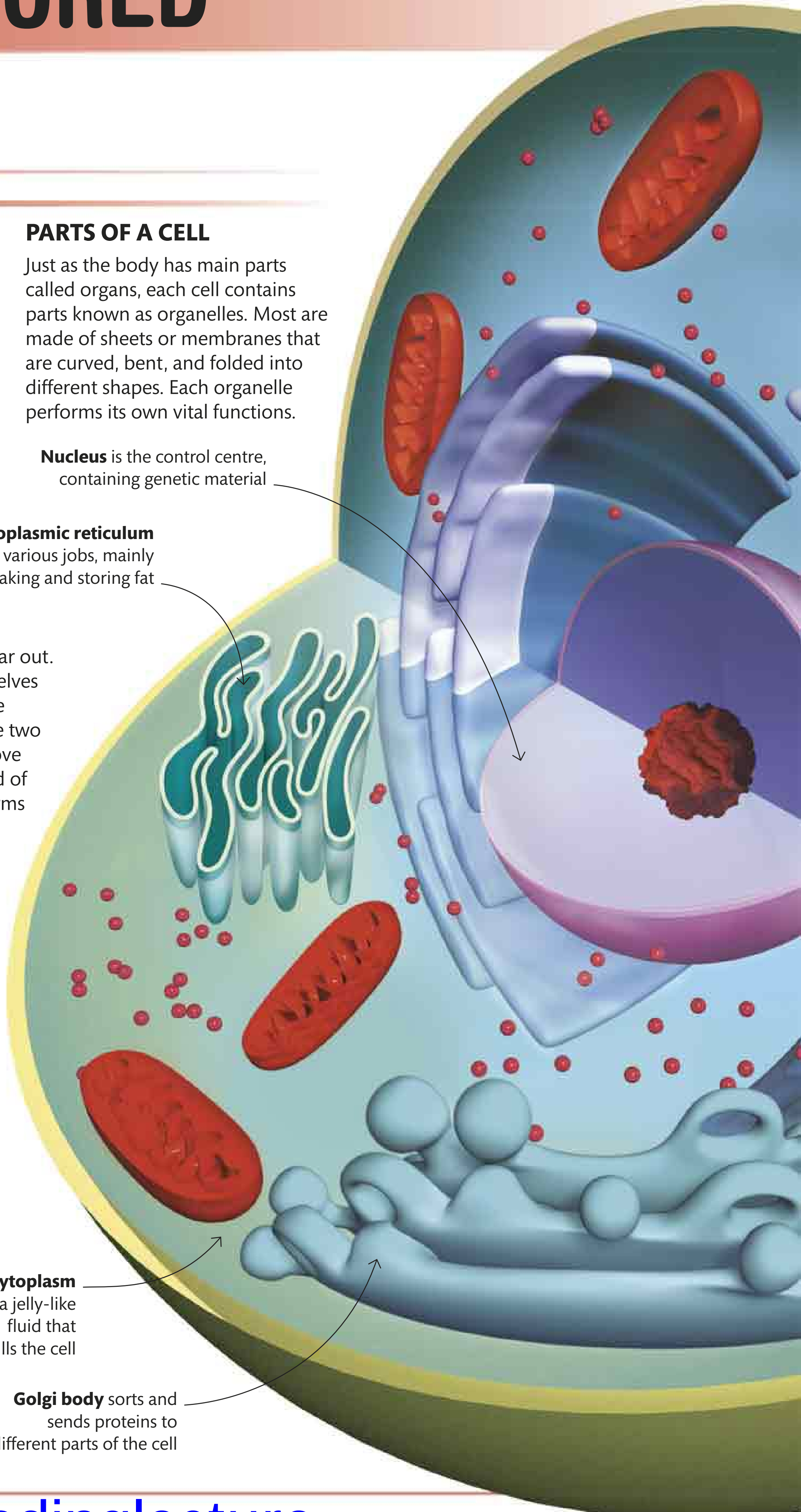
MINIATURE WORLD

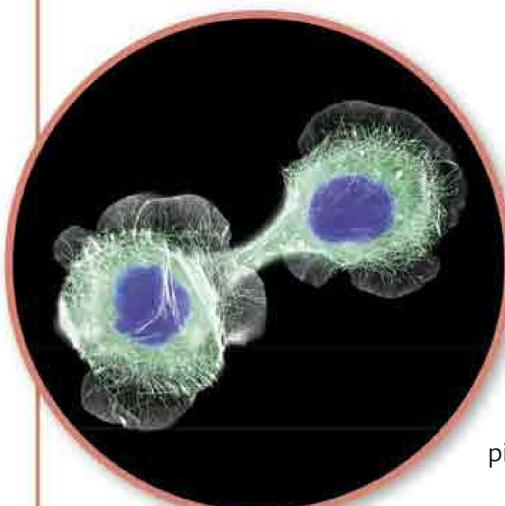
Inside a cell

The body is a gigantic collection of billions of living units called cells. They are busy with hundreds of parts and processes inside, yet they are truly tiny in size. If a typical cell was as big as you, the whole body it was in would be 100 km (62 miles) tall – up to the edge of space! There are more than 200 different kinds of cells. Each has a distinctive shape, design, and inner parts, to do its specialized tasks.

PARTS OF A CELL

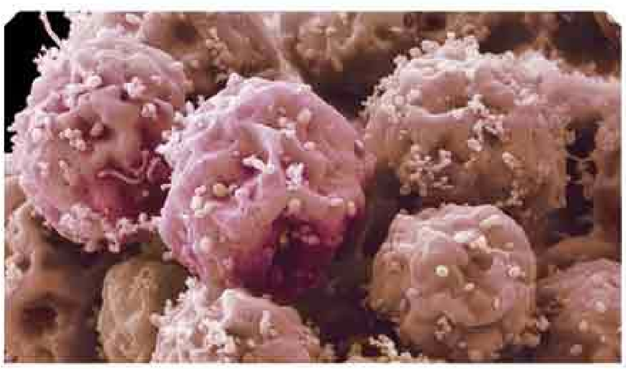
Just as the body has main parts called organs, each cell contains parts known as organelles. Most are made of sheets or membranes that are curved, bent, and folded into different shapes. Each organelle performs its own vital functions.





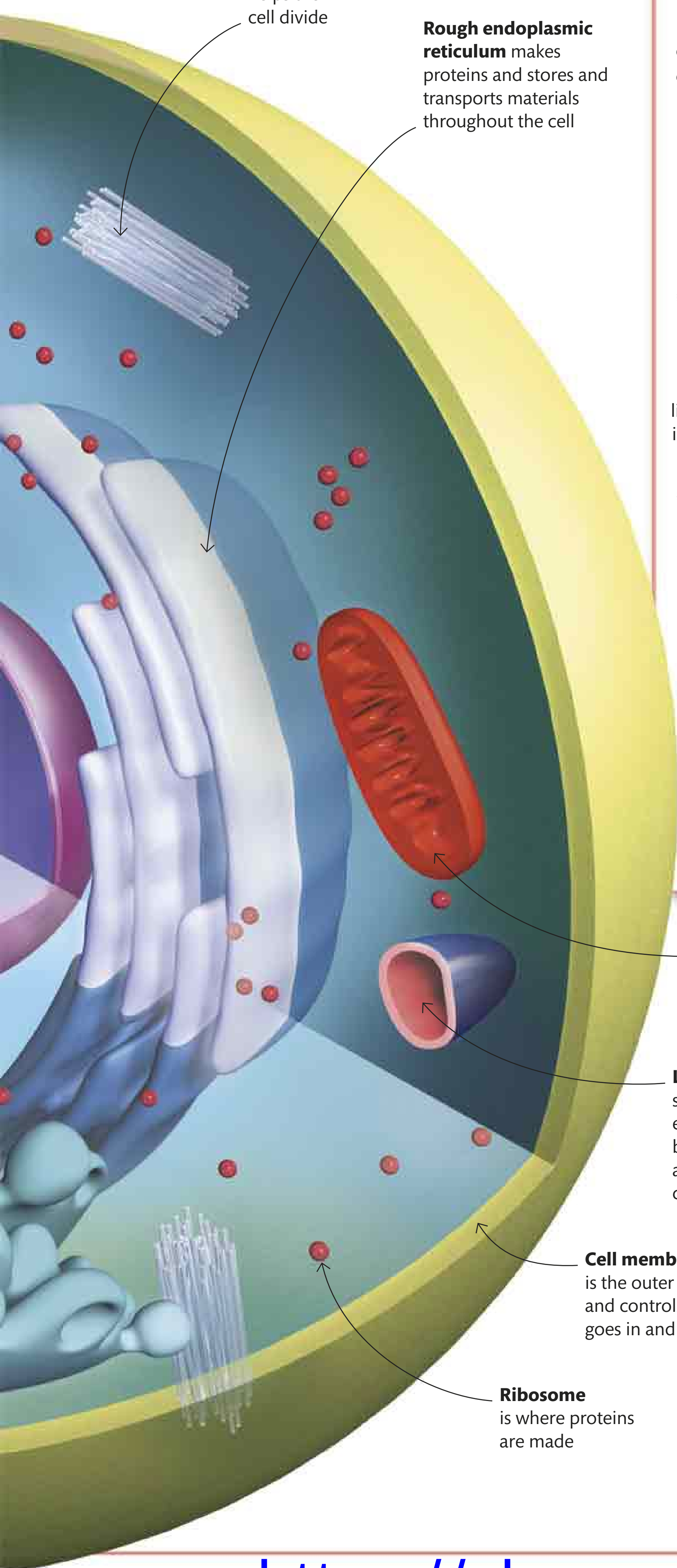
DIVIDING CELLS

Body cells continually wear out. They also replace themselves by cell division. First, the genes are copied to give two sets. These sets then move apart, one into each end of the cell, and a furrow forms in the centre. This furrow deepens and gradually pinches the cell into two.



STEM CELLS

Every human starts as a cell – the fertilized egg. This divides to make general-purpose, or stem, cells. While not specialized for any particular tasks initially, stem cells have the ability to divide further into any kind of specialized cell type. The type of cell they grow into depends on the signals they receive.



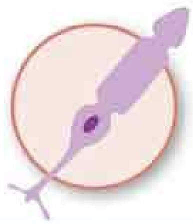
TYPES OF BODY CELLS

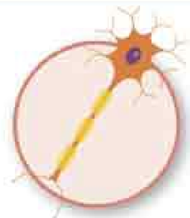
Most specialized cells include all the basic cellular parts, such as nucleus and mitochondria. But some parts may be larger and more numerous, depending on the cell's duties, such as making products, storage, or using energy. The cell's overall shape – long and thin, wide and rounded – also helps its function.

EPITHELIAL CELL
Shaped like bricks, blocks, or slabs, these make sheets that form coverings and linings of body parts.

SMOOTH MUSCLE CELL
Spindle-shaped, these cells can get shorter to make muscle contract.

LIGHT-SENSING CELL
The eye's rods and cone cells have light-sensing chemicals in one end and a nerve link at the other.





NERVE CELL
Thin, branching arms gather nerve signals and send them along the nerve fibre.

RED BLOOD CELL
Disc-shaped, it soaks up maximum oxygen to carry the highest amount possible in the bloodstream.

SPERM CELL
The head carries the father's genetic material. The tail lashes to swim towards the egg.

ADIPOSE FAT CELL
Most of the cell is filled with large blobs of fat – a valuable store of energy for tissues.

EGG CELL
This contains the mother's genetic material and large energy stores for early cell divisions.

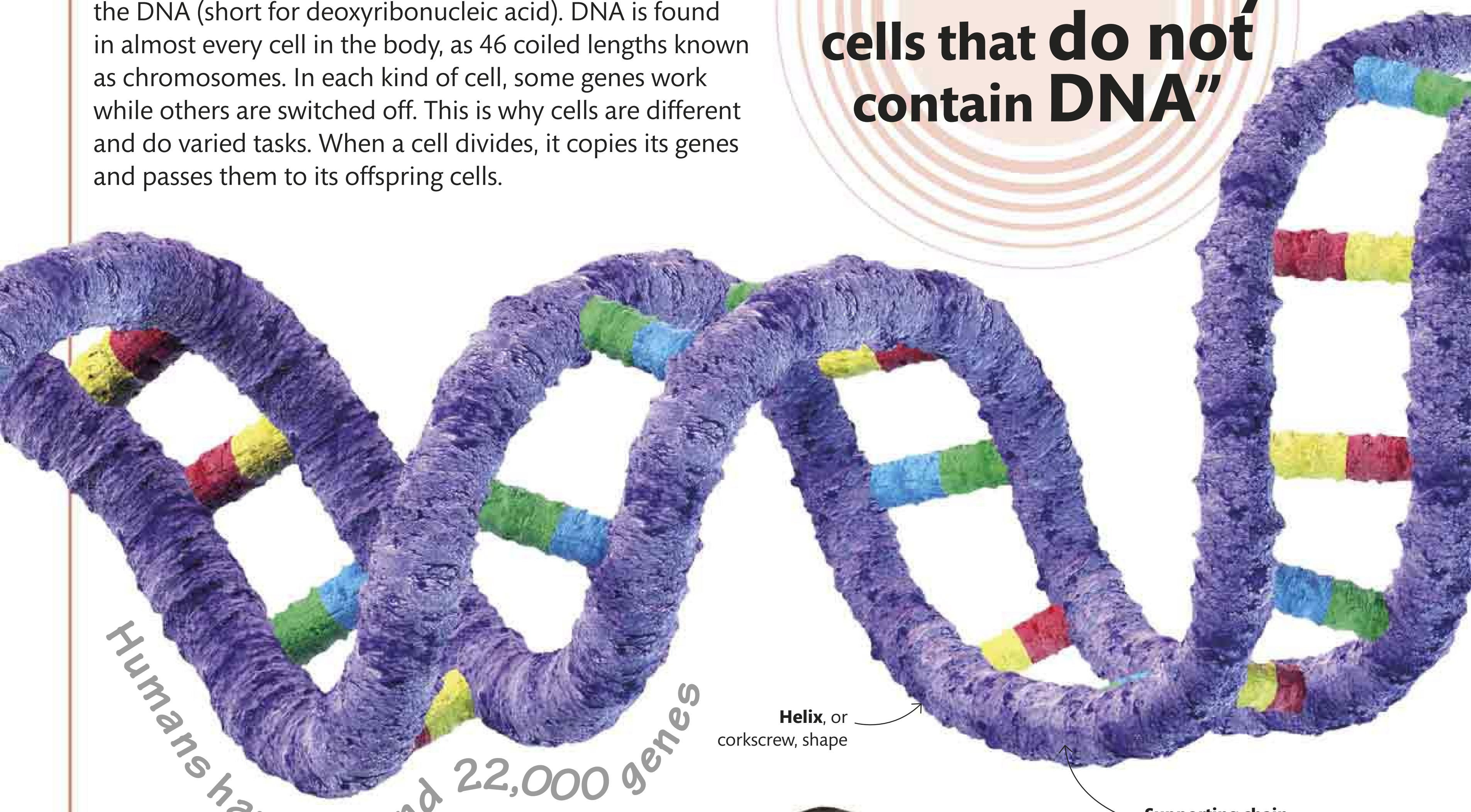
"Every human spends about one day as a single cell"

THE HUMAN CODE

DNA and genes

Every living body needs instructions on how to work as well as how to repair its old parts and build new ones. The instructions, genes, come in the form of chemical codes in the DNA (short for deoxyribonucleic acid). DNA is found in almost every cell in the body, as 46 coiled lengths known as chromosomes. In each kind of cell, some genes work while others are switched off. This is why cells are different and do varied tasks. When a cell divides, it copies its genes and passes them to its offspring cells.

"Red blood cells are the only cells that do not contain DNA"



DNA SUPERHELIX

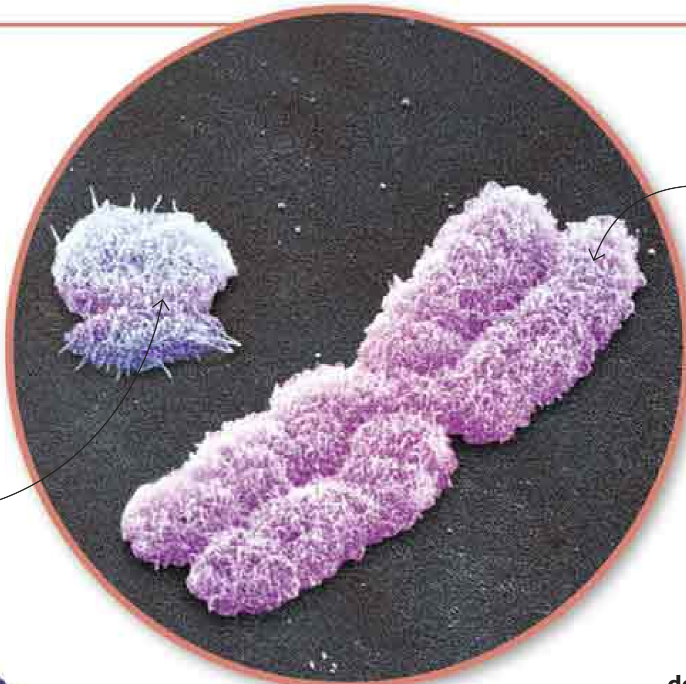
A length of DNA has a double-helix shape, and resembles a long twisted ladder. This ladder's "rungs" are made up of four chemicals – adenine, cytosine, guanine, and thymine – called bases. The bases are always linked in pairs – adenine with thymine, and cytosine with guanine. A specific order of bases forms an instruction, called a gene, that controls a part of the body, such as skin or hair colour.

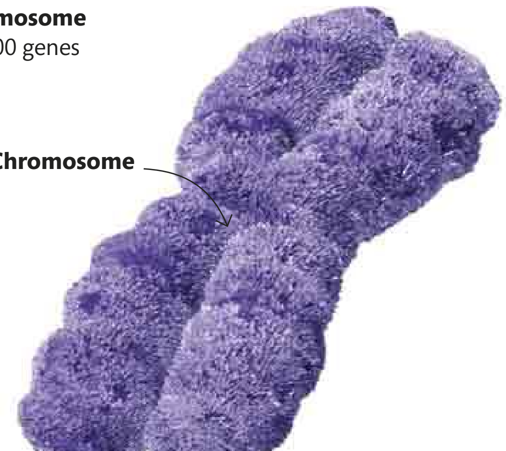
GENES PASSED ON

A baby is created when an egg from the mother joins a sperm from the father. Both egg and sperm contain genes, so the baby has two sets, one from the mother and one from the father. This is why most children resemble both their parents.

BOY OR GIRL?

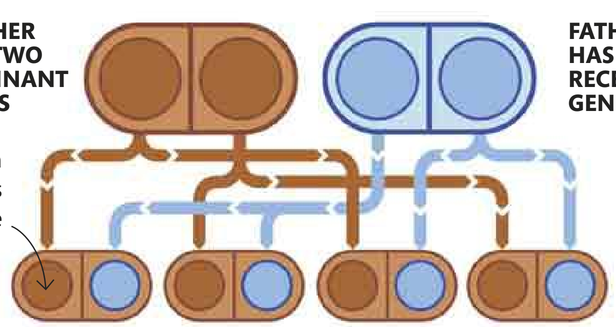
Two of the 46 chromosomes are known as sex chromosomes. One has an X shape; the other is shaped like a Y. Females have two Xs, XX, so a mother can only pass an X to her baby. Males have an X and Y, XY, so a father may pass on either. If the baby receives a Y from its father, it is XY – a boy. If it receives an X it is a girl, XX.



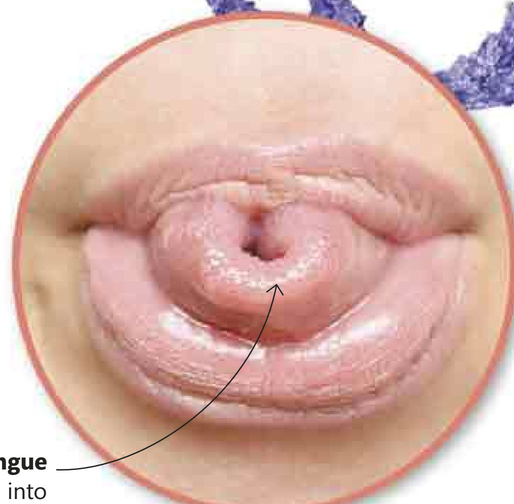


HOW GENES WORK TOGETHER

The body has two complete sets of genes, one from each parent. That means we get two versions of every gene. These two versions may be different. For example, one of the genes that determines eye colour may make blue eyes and the other brown. Which wins? Some genes are dominant and they beat the other ones, called recessive.



ALL OFFSPRING HAVE THE SAME COMBINATION



TONGUE-TIED

Recent discoveries about the body show that many features are controlled by several genes, rather than just one. Eye colour, for example, is the result of two main genes plus at least six others, perhaps as many as 15. These genes do not work separately but affect each other in various ways. Tongue-rolling is another example where several genes are involved.


1

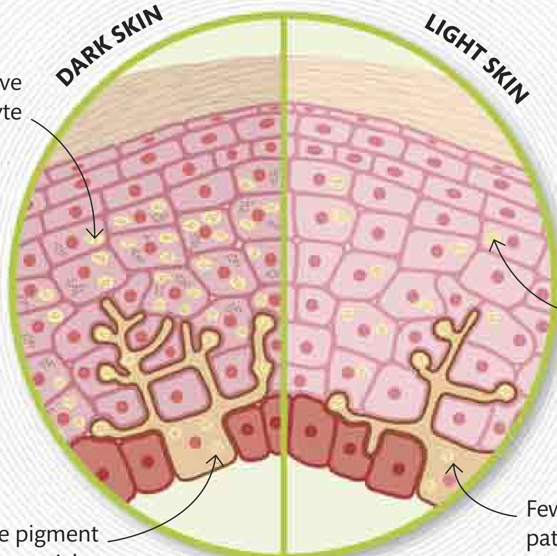
BODY FRAMEWORK

Stiff yet bendy, hard but soft, powerful yet delicate – bones, joints, and muscles are our all-action mobile framework. They are clothed in a tough coat of skin that is always worn yet never wears out.

BODY ARMOUR

What skin does

Take a close look at your skin – almost everything you see is dead! Its outer layer, or epidermis, consists of dead cells that rub off and are replaced by new cells from below. This flexible, self-renewing layer protects us against dirt, germs, and injury. Deeper in the skin, the dermis is very much alive and provides our sense of touch.



COLOUR CODING

The epidermis contains coloured substances, or pigments, that are made by cells called melanocytes. Granules of pigment are stored in melanosomes and released in strong sunlight to protect the skin. Dark skin produces more melanin (brown pigment) than light skin.

STATS AND FACTS

SKIN THICKNESS

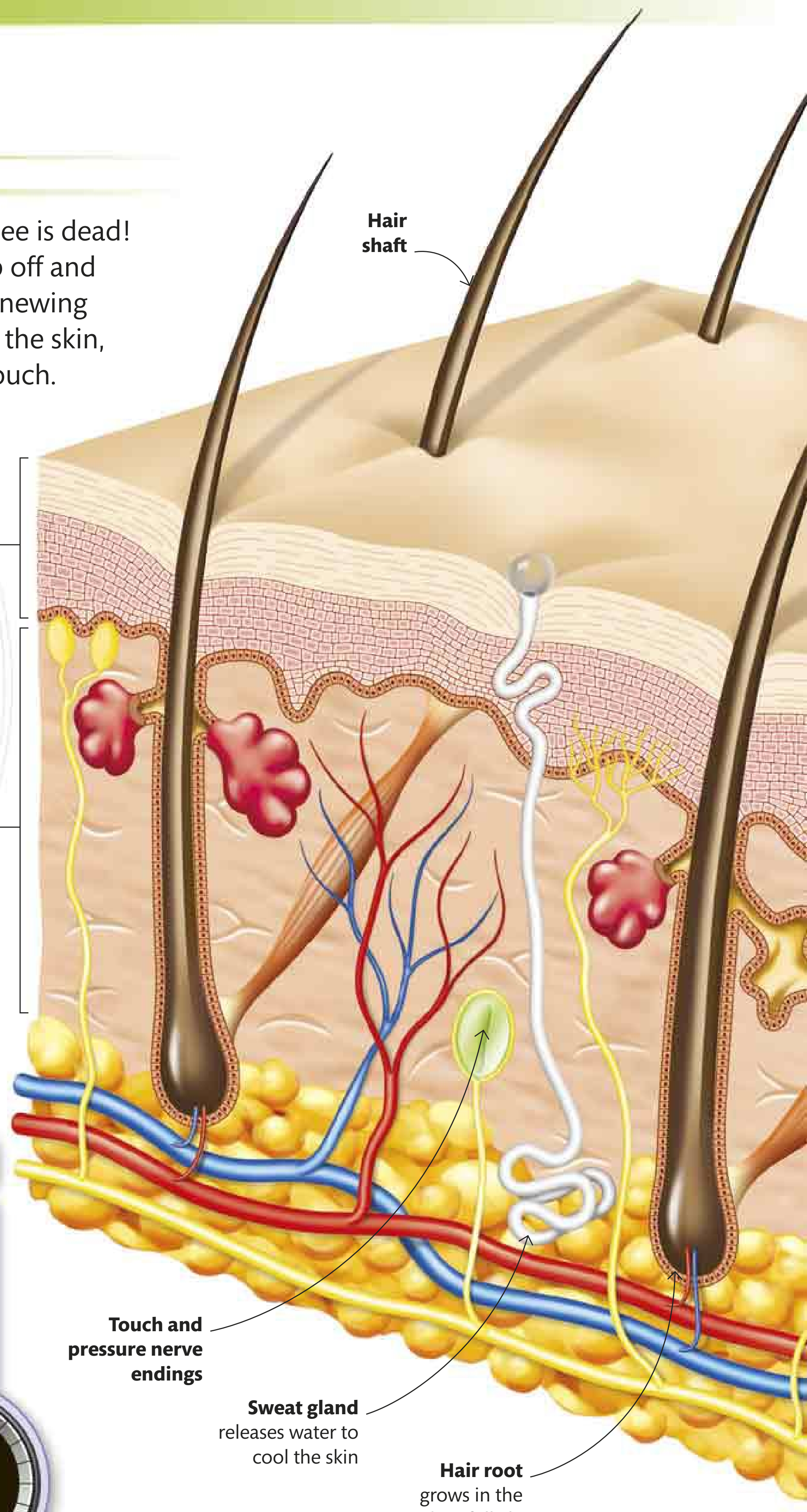
EYELID 0.2 mm

FOOT SOLE 1.5 mm

SKIN SHEDDING

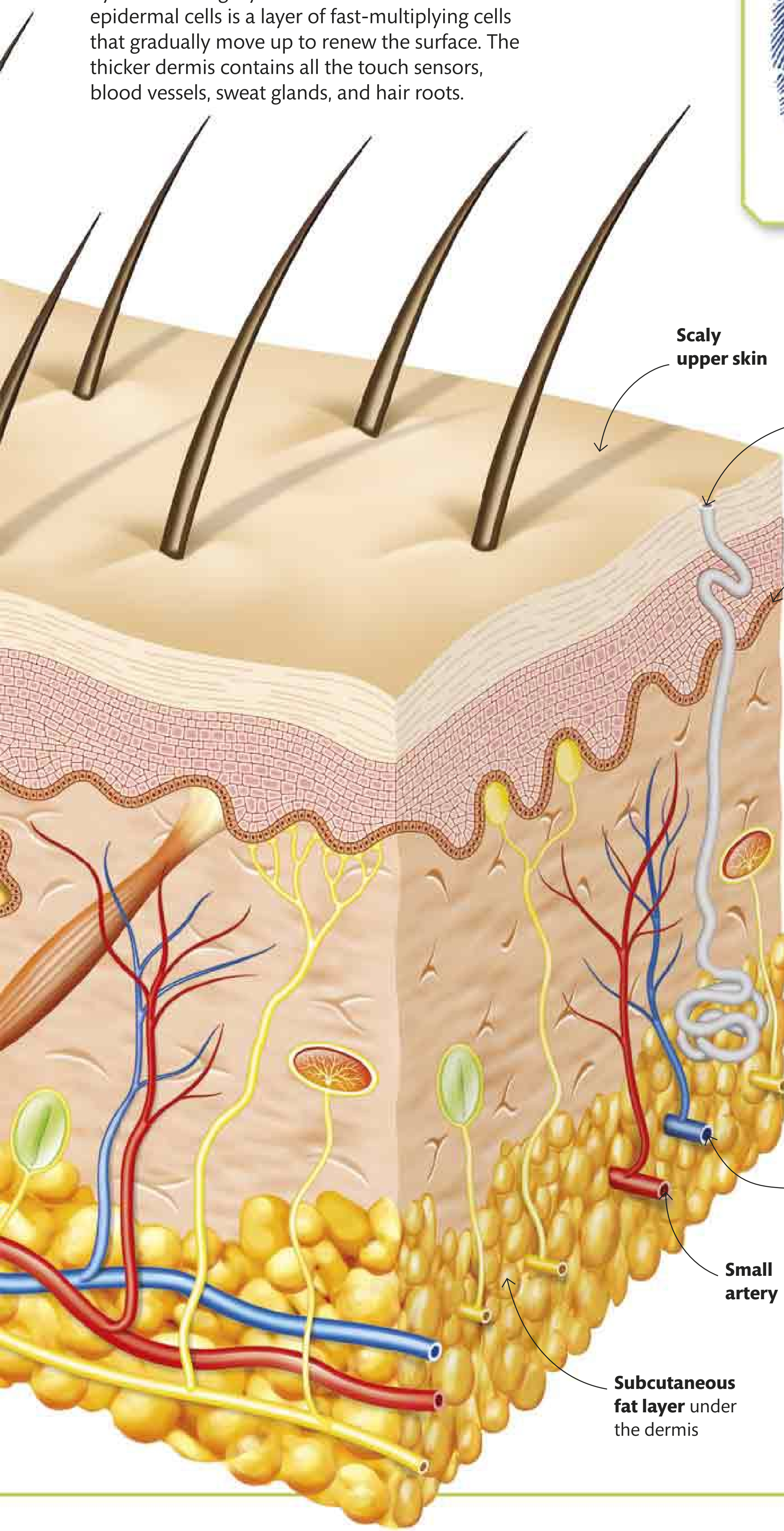
50% of dust is dead skin in your home

SKIN RENEWAL TIME 27 DAYS



BELOW THE SURFACE

The skin is made up of two layers, underpinned by an insulating layer of fat. Below the dead epidermal cells is a layer of fast-multiplying cells that gradually move up to renew the surface. The thicker dermis contains all the touch sensors, blood vessels, sweat glands, and hair roots.



FINGERPRINTS

The skin on your fingers, palms, soles, and toes is patterned with ridges and grooves that form curves, loops, whorls, and swirls. These ridges make it easier to grip small or smooth objects. Every finger has a different pattern, which can be pressed onto paper to provide a set of prints that are unique to you.

THE SKIN IS THE LARGEST ORGAN OF THE HUMAN BODY

NATURAL OVERCOAT

This close-up view of the skin's surface shows how the flattened dead cells overlap like roof tiles. Made of tough keratin, they form a hard-wearing yet disposable protective barrier.

"Your body sheds up to 50,000 flakes of skin every minute"

SWEAT AND SHIVER

Body temperature

The human body works best at a temperature of 37°C (98.6°F), give or take half a degree. Cooler or warmer temperatures upset the delicate balance of the body's thousands of chemical processes, called metabolism. The skin, along with the muscles and tiny blood vessels just under the surface, plays a major role in keeping body temperature within these narrow limits.

Too hot

Deep in the brain, the temperature centre monitors the blood. Above about 38°C (100.4°F), the sweat glands produce watery sweat. As the sweat evaporates, it draws heat from the skin and inner parts, and cools the body down.

We sweat 1.5 l (3 pts) an hour in severe heat

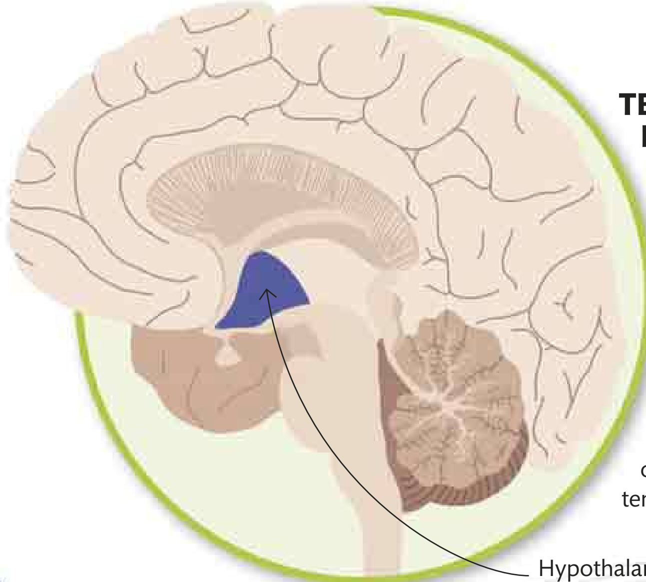
Athletes sweat easily because they have a more efficient body thermostat

Sweat is mostly water but contains around 1% dissolved minerals

WHICH BITS ARE HOTTEST?

An infrared or heat-sensitive image shows the range of body surface temperatures, red being warmest and blue coolest. The head and extremities such as the ears and fingers have less fat, and cover a greater surface area for their volume or bulk, so they lose heat rapidly. The main body, with less surface area for its volume and a layer of insulating fat under the skin, stays warmer.

"Shivering can burn about 400 calories per hour"



TEMPERATURE REGULATION

A tiny cluster of cells in a fingertip-size part of the brain, the hypothalamus, detect the warmth of blood flowing past. They also receive messages from the skin, then send out nerve signals to control sweating, shivering, and other processes to regulate temperature.

Too cold

When the brain detects a fall below around 36.5°C (97.7°F), it takes action to retain heat within the body. The muscles contract fast, or shiver, to produce extra heat, and the blood is kept away from the body's surface, where it would lose heat.

GOOSEBUMPS

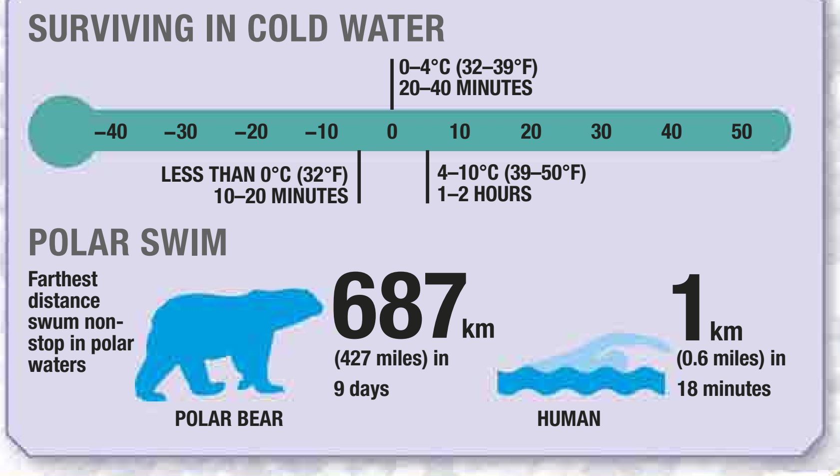
Each body hair has a tiny muscle that can contract to pull the hair more upright. When many hairs do this, small skin mounds, called goosebumps, appear. The hairs trap warm air near the skin, providing insulation.

ICY PLUNGE

Survival strategy

Gasp! A human body plunging into icy water instantly starts battling to survive. Panting allows the lungs to gulp in air for extra oxygen – also needed if the body goes under. The heart rate slows by as much as one-fifth, saving energy and reducing blood flow to the limbs to reduce heat loss. Small blood vessels narrow in the hands and feet, then arms and legs, also slowing heat loss. This keeps most of the blood, with its energy and oxygen, going to the brain and other vital organs.

STATS AND FACTS



Ice bath

Cold water rapidly affects your ability to swim, because movement lowers your body temperature. Survival time in icy water is 10–20 minutes, depending on physical fitness and thickness of under-skin fat.

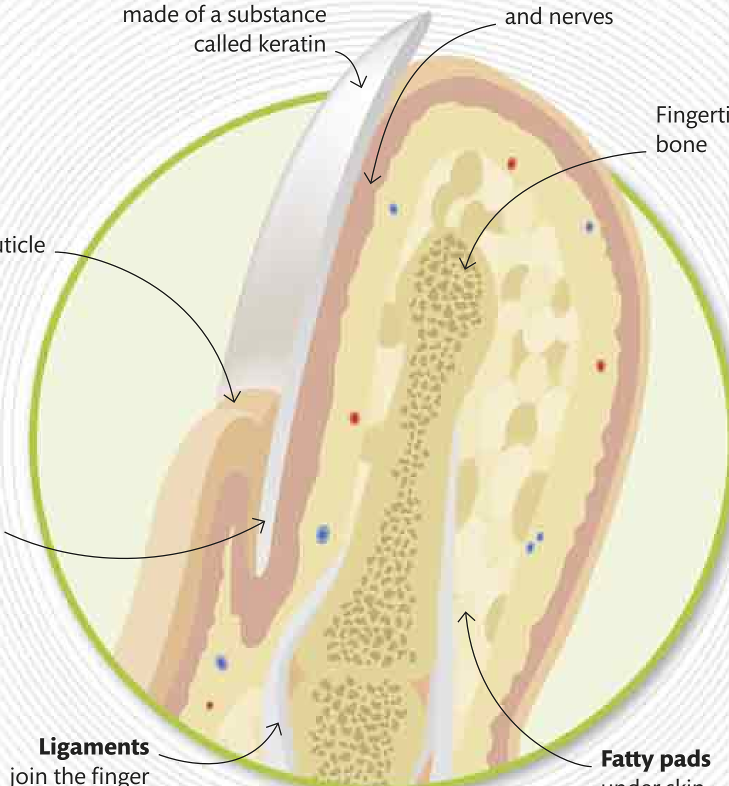
"Cold water takes away body heat 30 times faster than cold air"

FINISHING TOUCHES

Hair and nails

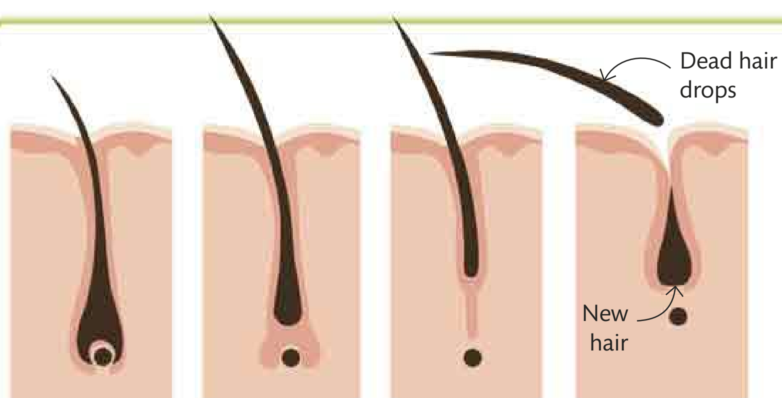
Hair and nails are almost entirely dead, otherwise trimming them would hurt! Both grow and lengthen from their roots in the skin. They are made from squashed-together dead cells that contain the same tough protein as the outer layer of the skin – keratin. There are many different types of hairs, including long scalp hairs on the head, face and body hairs, underarm hairs, eyebrows, eyelashes, and thicker facial hair in men. Each type has its own thickness, growing speed, and life cycle.

"The middle fingernail grows the fastest, and the thumbnail, the slowest"



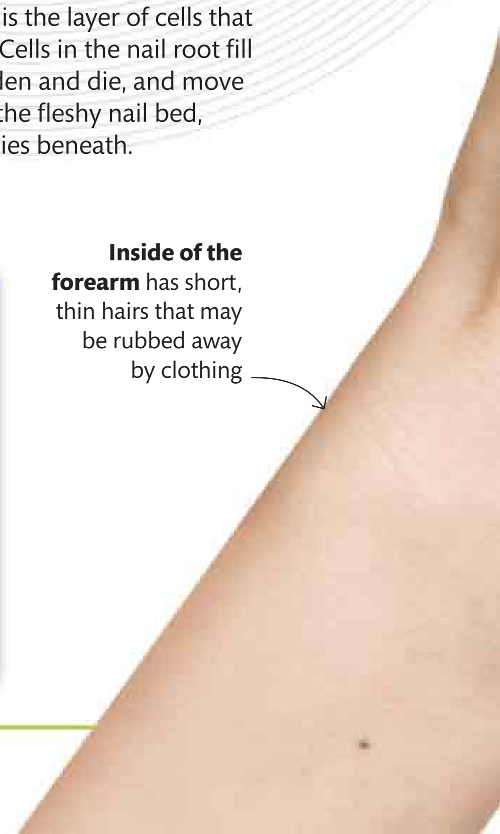
HOW NAILS GROW

A nail emerges from a fold of skin under the cuticle, which is the layer of cells that produces keratin. Cells in the nail root fill with keratin, harden and die, and move slowly along the fleshy nail bed, which lies beneath.



THE LIFE OF A HAIR

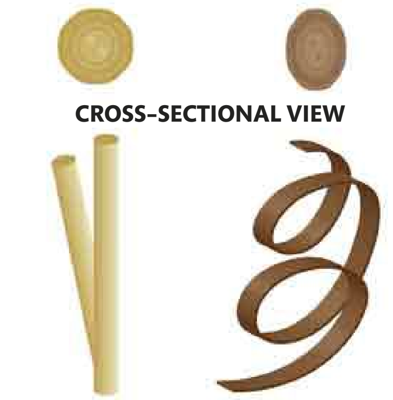
Each head hair has a limited life. Its growth phase lasts 2–6 years, so most hairs never grow longer than 1 m (3 ft) – hair grows about 0.3 mm a day. It then goes through a period of transition that lasts 10–14 days, when the follicle shrinks. A resting phase of 4–6 weeks follows, during which growth stops and the hair falls out. Gradually, the follicle recovers and a new hair grows.



Inside of the forearm has short, thin hairs that may be rubbed away by clothing

CURLY OR STRAIGHT

The colour and waviness of scalp hairs is mainly due to genes inherited from parents. In cross-section, curly hairs tend to be oval or elongated, while straight hairs are rounded or circular. Brown-haired people usually have 100,000 hairs on their head, blondes have about 120,000 hairs, and redheads have 90,000 or fewer.



HAIRY ALL OVER

You have hair almost everywhere except your lips, palms of your hands, and soles of your feet. However, some are too tiny or too thin to see without a magnifier. Each hair grows from a deep pouch-like pocket in the skin, called a hair follicle.

The longest recorded hair is 5.6m (18ft)

WE LOSE 80–100 SCALP HAIRS A DAY

CUTTING EDGE

Nailing it

Unlike hairs, which grow, die, and fall out, nails grow day after day, year after year. They help to scratch off dirt and pests such as fleas, ease itches, and pick up tiny objects. A nail is also a hard plate that protects the soft fingertip under it, and helps us sense how hard the tip is pressing. But as a nail lengthens, it collects dirt and germs, and it may snag and break. Any pain is felt in the sensitive patch of skin under the nail, called the nail bed, since the nail itself is dead.

STATS AND FACTS

AVERAGE NAIL THICKNESS

1.5 mm (1/16 in)
Toenail

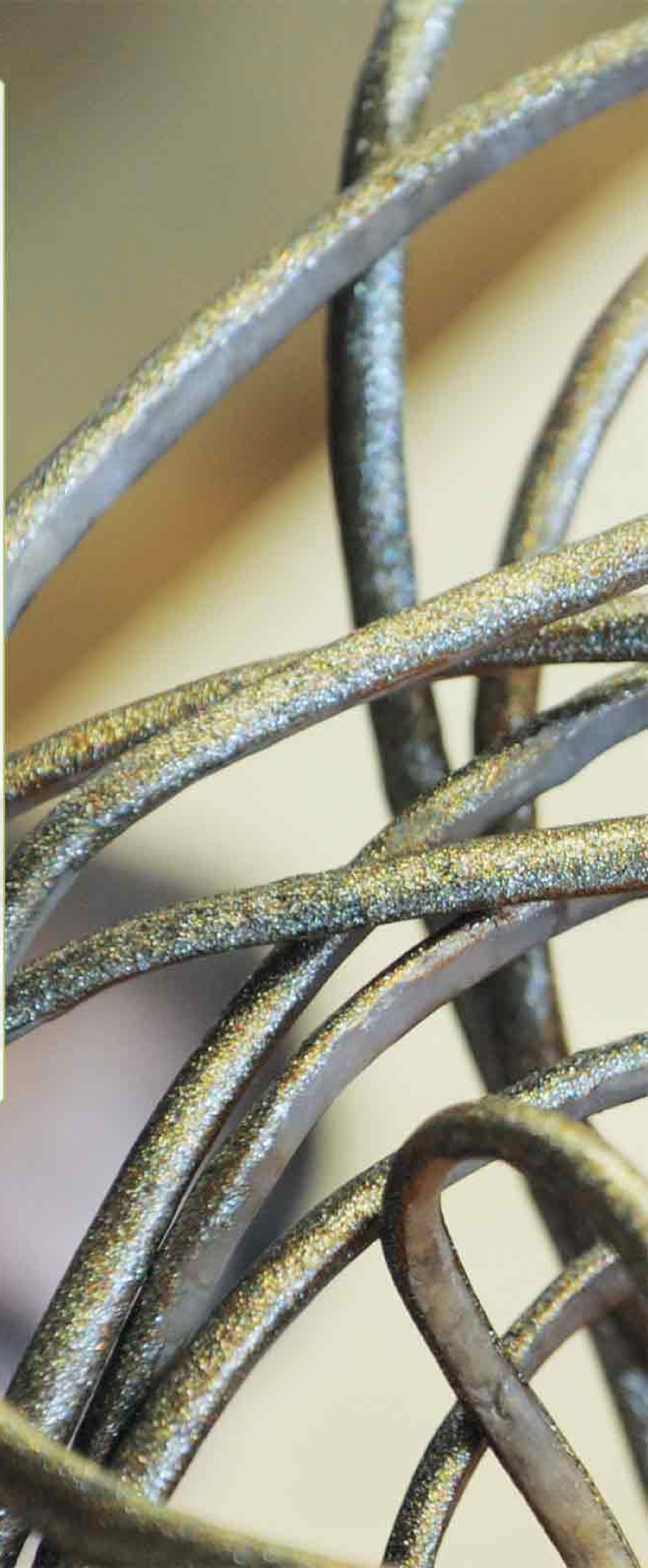
0.5 mm
Fingernail

LONGEST SINGLE NAIL

1.3 m (4½ ft)

A fingernail grows 1 cm (½ in) every 100 days

WATER CONTENT OF NAILS
10–15 PER CENT



Tangled talons

Uncut nails tend to curve and curl because of tiny differences in the growth rates of the left and right side of a nail, and also of its upper and lower surfaces. Nails grow faster on the hand you use the most.

"Nails grow faster in summer than in winter"

BODY SUPPORT

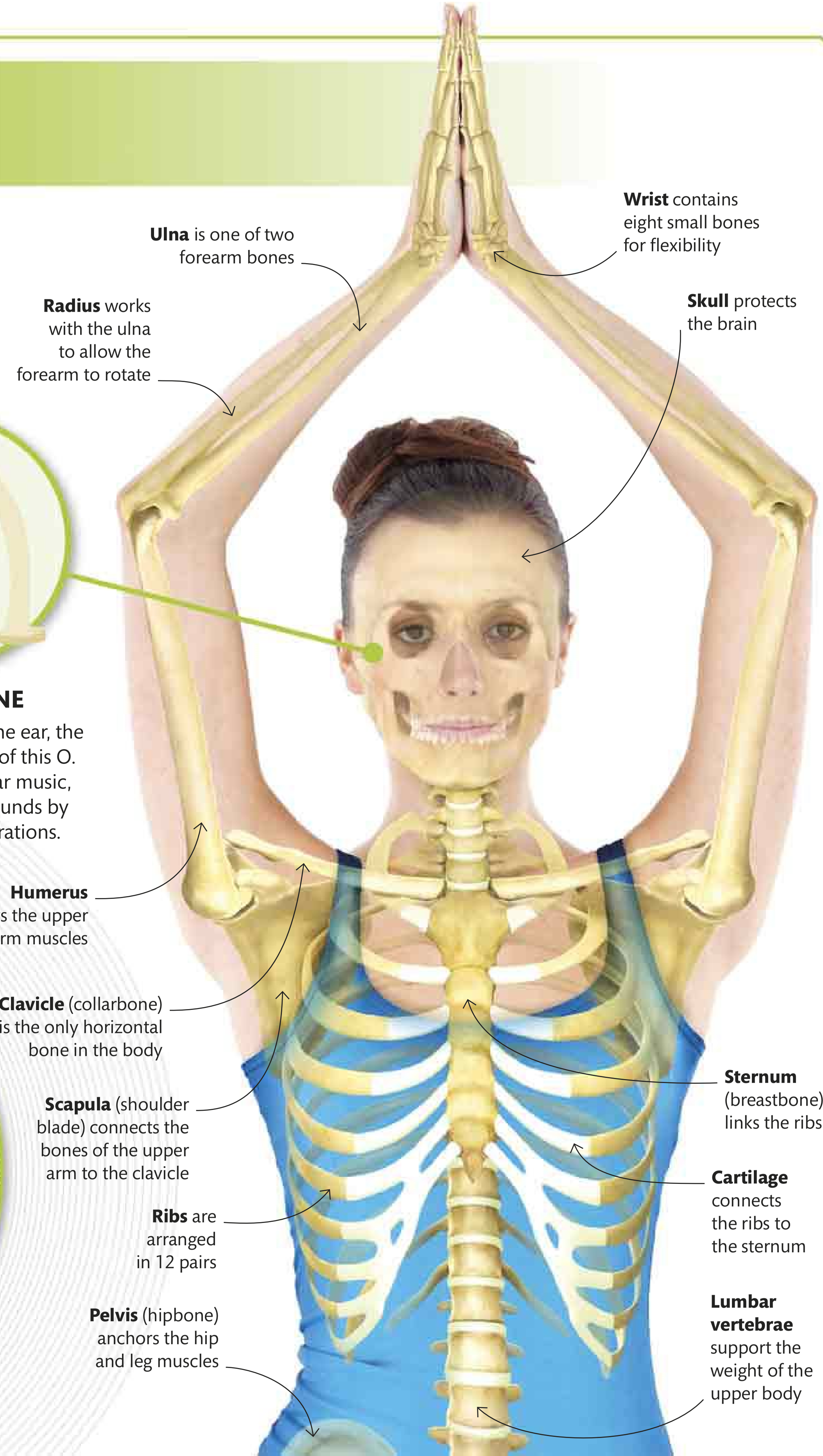
Skeleton

Far from being dry, white, and dead, your skeleton – all the bones put together – is one-quarter water, pinkish-white in colour, and an active part of the body. Not only does the skeleton prevent you from collapsing into a heap of meat, it is a moveable frame that helps you stand, walk, run, jump, lift, and push. It also protects organs such as the brain, spinal cord, heart, and lungs. The skeleton contains vital stores of key minerals, and every second it makes millions of new blood cells.

Actual size is 2.5 mm (1/10 in)

TINIEST BONE

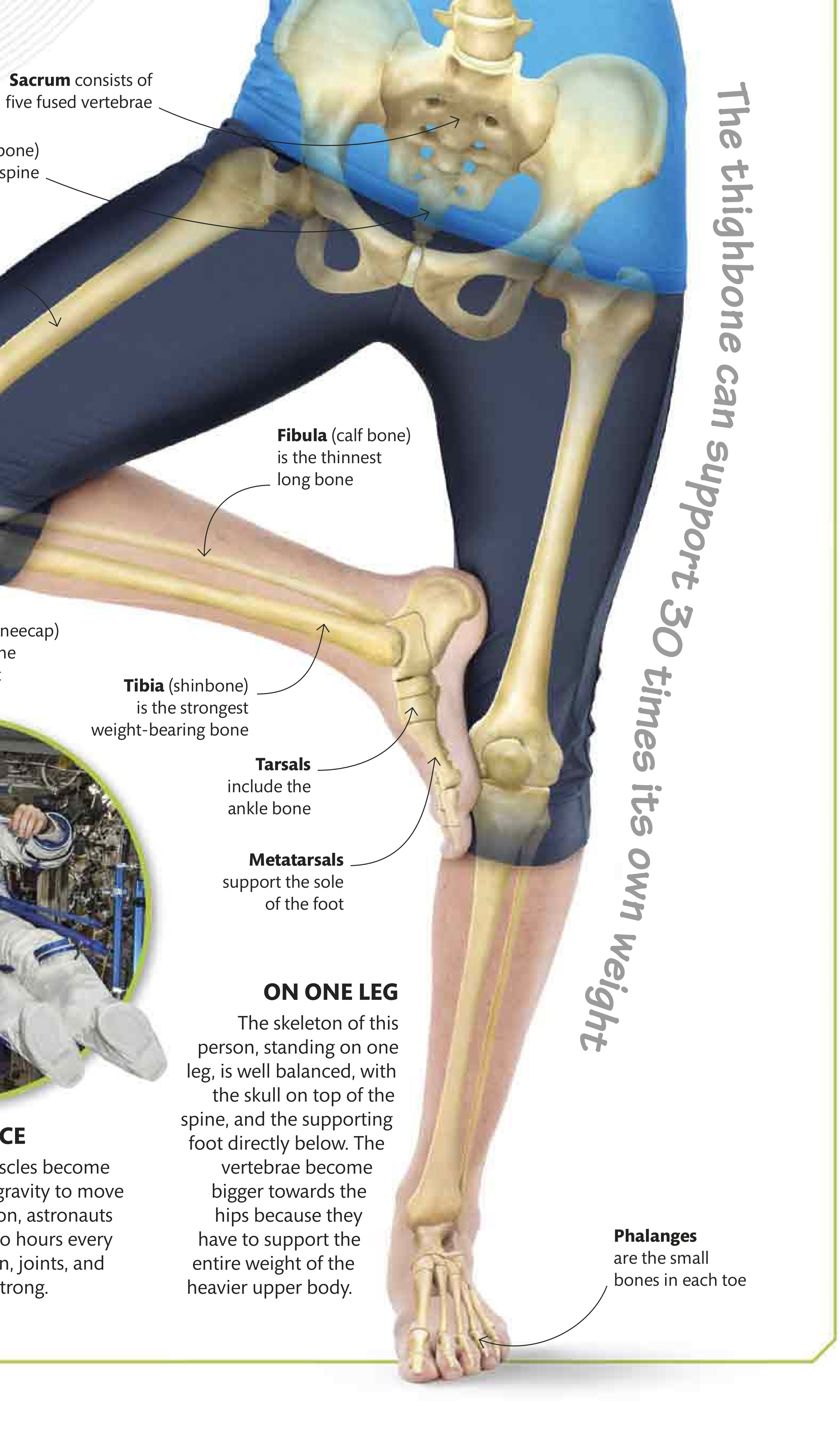
Located deep within the ear, the stirrup is just the size of this O. Yet it allows us to hear music, speech, and other sounds by passing on their vibrations.



YOUR SKELETON HAS 206 BONES

BENDY SPINE

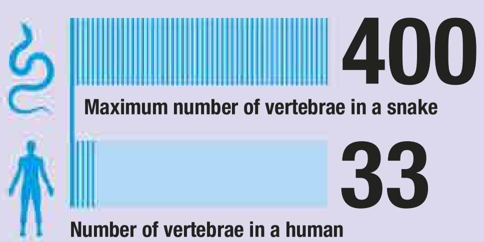
The skeleton's central column of bones, or vertebrae, makes up the spinal column. Each joint between the bones moves only a small amount, but the movement adds up along the entire spine so that you can bend almost double.



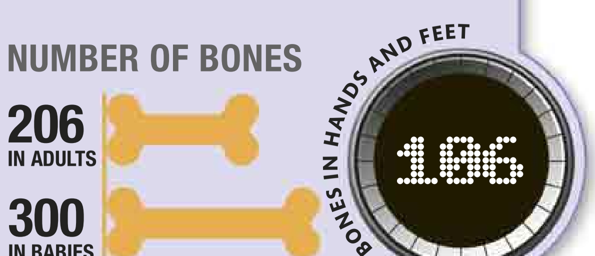
"Humans and giraffes both have seven neck bones"

STATS AND FACTS

NUMBER OF VERTEBRAE



NUMBER OF BONES



BONES IN SPACE

In space, bones and muscles become weak without the pull of gravity to move against. On a long mission, astronauts must exercise at least two hours every day to keep the skeleton, joints, and muscles fit and strong.

ON ONE LEG

The skeleton of this person, standing on one leg, is well balanced, with the skull on top of the spine, and the supporting foot directly below. The vertebrae become bigger towards the hips because they have to support the entire weight of the heavier upper body.

SUPER LEVERS

Record leaps

The human skeleton is a marvel of engineering that uses many of the same mechanical principles as a machine. Muscles that move limb bones are attached near joints. When such a muscle contracts a small distance, it moves the other end of the bone, like a lever, by five to ten times more. This movement is passed to the next bone of the limb, further increasing the motion. Athletes make use of this multilever effect to propel their bodies over incredible distances at amazing speeds.

STATS AND FACTS

HIGH JUMP RECORD

MEN: **2.4 m** (7 9/10 ft)

WOMEN: **2.05 m** (7 ft)

LONG JUMP RECORD

8.95 m (29 2/5 ft)

Achieved by Mike Powell from USA in Tokyo, Japan on 30 August 1991

CHAMPION LONG JUMPER

10 m/sec (33 ft/sec) Long-jump speed at takeoff

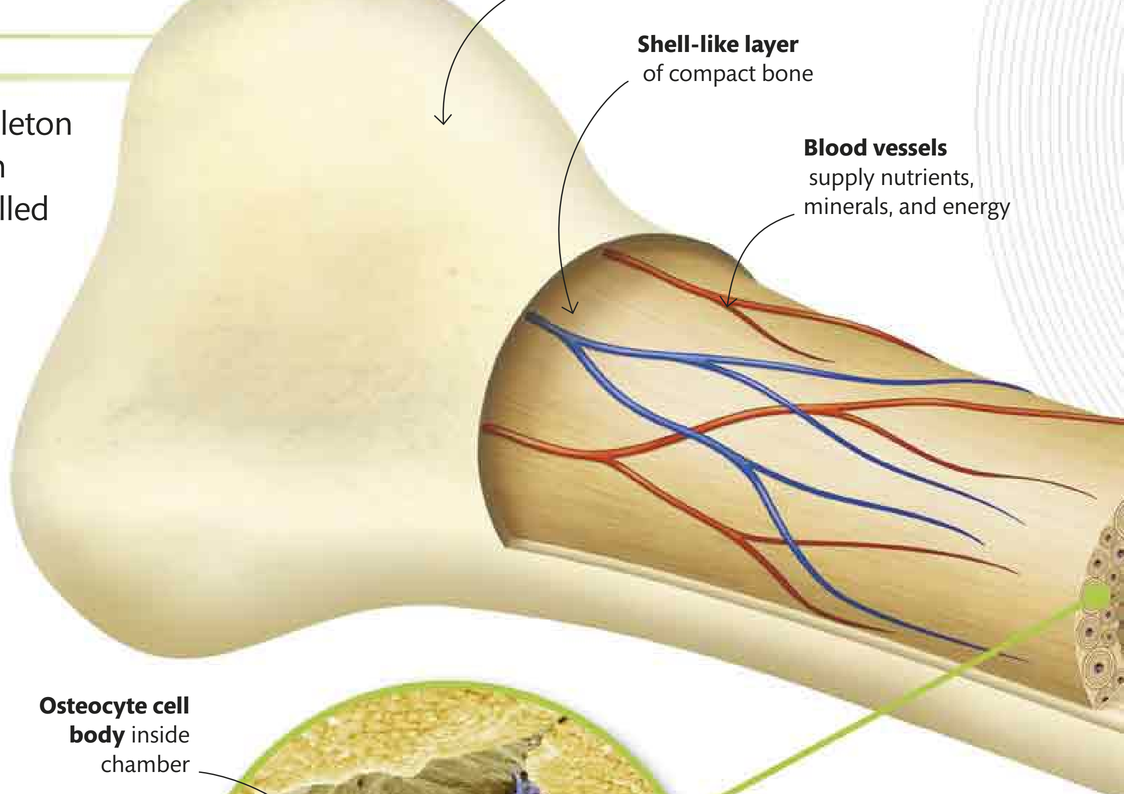
Fast flight
As this long jumper hits the takeoff board, her power leg straightens the hip, knee, ankle, and toe joints in turn. All her leg bones together convey the forward and upward forces to the rest of the body.

"Champion long jumpers can leap 5 times their body length"

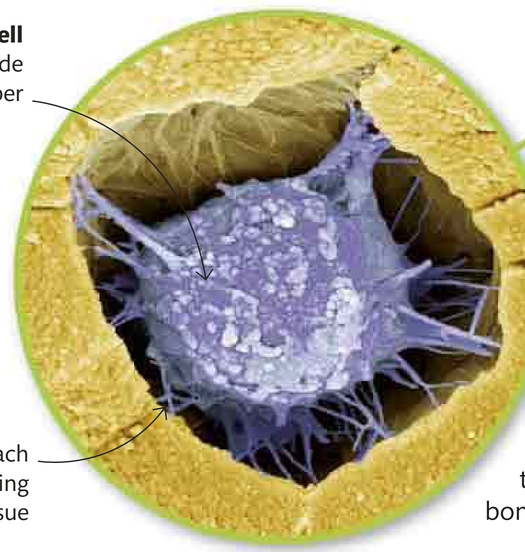
BARE BONES

Inside bone

Bones are far from solid – otherwise your skeleton would be five times heavier! Each bone has an outer shell of a very strong, dense substance called compact bone. Inside it is a more sponge-like layer, which has struts and rods of bone with spaces between for fluids and other tissues. This clever design makes bones light, but strong, like honeycomb. In the middle of most bones is jelly-like bone marrow.



"Bones can support more weight than concrete"

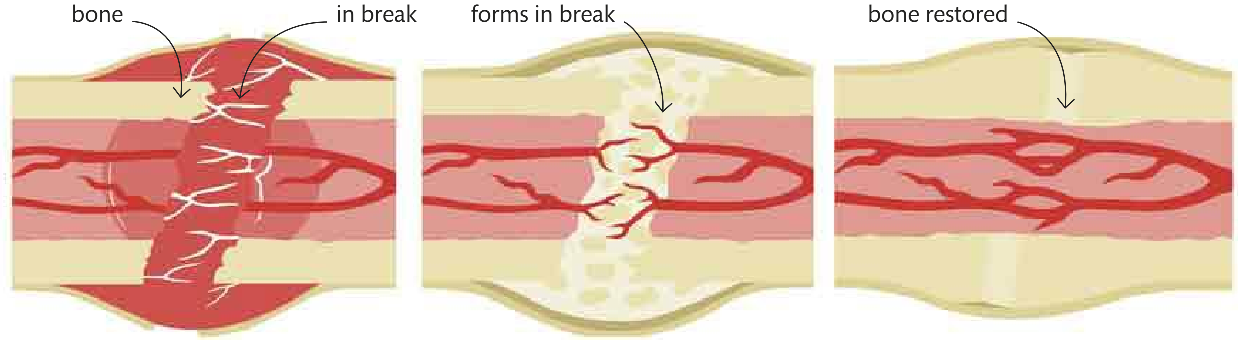


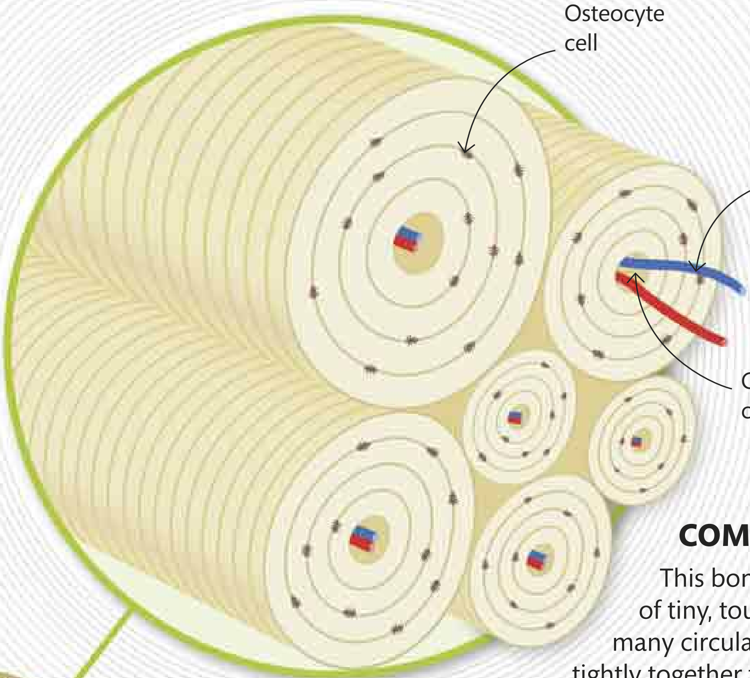
TRAPPED IN

Compact bone is full of tiny chambers that contain cells called osteocytes. Each cell lives for tens of years trapped inside its chamber, where it helps to maintain the surrounding bone and keep it healthy.

REPAIRING BONE

A broken or cracked bone starts to repair itself almost straight away. Blood clots in the break to stop further leaks. White blood cells gather to fight infection and clear away dead cells and tissues. Other cells make fibres that grow between the broken ends. Cells called osteoblasts then produce spongy bone which, in the outer layer, hardens into compact bone.





STATS AND FACTS

BONE COMPOSITION

10% ORGANIC MATTER

65% MINERALS

25% WATER

WHAT BONES STORE

99% of the body's CALCIUM

60% of the body's MAGNESIUM

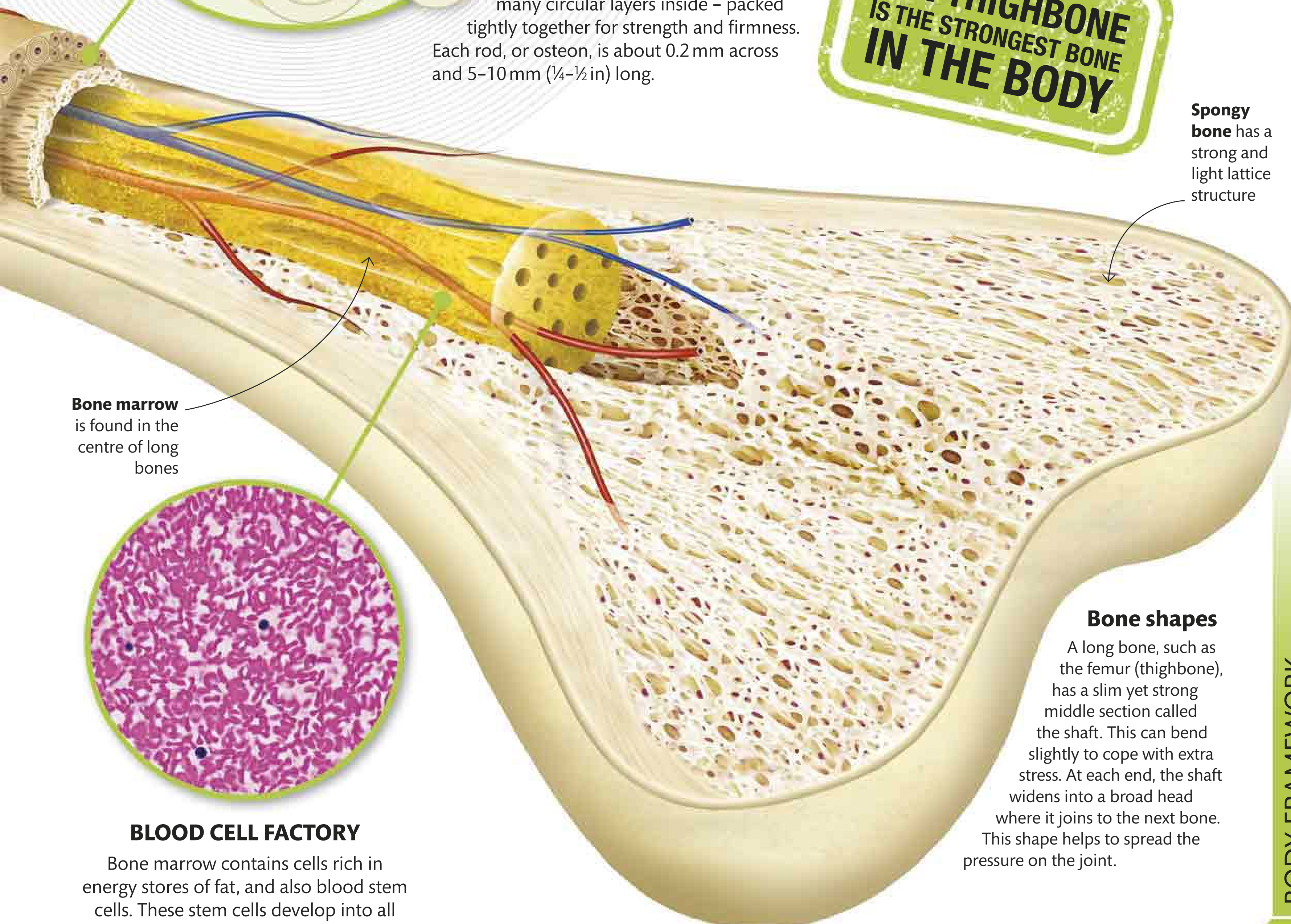
BONE REPLACED EACH YEAR

0.1 PER CENT

COMPACT BONE

This bone consists of hundreds of tiny, tough rods – each with many circular layers inside – packed tightly together for strength and firmness. Each rod, or osteon, is about 0.2 mm across and 5–10 mm (¼–½ in) long.

THE THIGHBONE IS THE STRONGEST BONE IN THE BODY



BLOOD CELL FACTORY

Bone marrow contains cells rich in energy stores of fat, and also blood stem cells. These stem cells develop into all the different types of blood cell – red cells, white cells, and platelets.

Bone shapes

A long bone, such as the femur (thighbone), has a slim yet strong middle section called the shaft. This can bend slightly to cope with extra stress. At each end, the shaft widens into a broad head where it joins to the next bone. This shape helps to spread the pressure on the joint.

BEND AND SWIVEL

How joints work

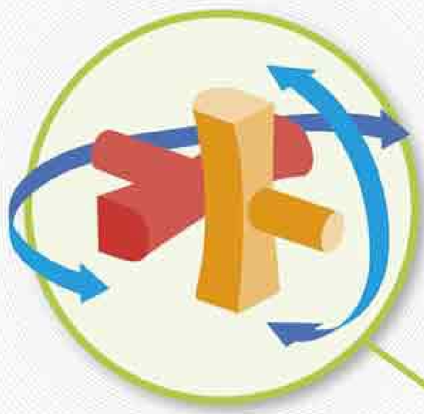
From the smallest finger knuckle to the big, sturdy knee, the body has more than 400 joints. Here bones come together and are linked to each other. Most familiar are the moveable joints, which occur from the jaw down to the toes. Each moveable joint has its own design that combines flexible freedom of movement with enough strength and stability to ensure that the bone ends do not come apart. But there are also fixed joints – in the skull, lower backbone, and hipbones – where the bones are stuck together with a kind of living glue.

PIVOT

The joint between the the base of the skull and the uppermost bone of the spine is like a dome that fits into a socket. This joint allows the head to move from side to side.

ELLIPSOIDAL

Some of the eight wrist bones have oval-shaped surfaces that fit together like an egg in an eggcup. The bones tilt as they roll against one another.



SADDLE

The bones of the joint at the base of the thumb have a double-curved shape, like a horse's saddle. They can tilt in any direction but cannot twist.

The smallest joint is in the ear

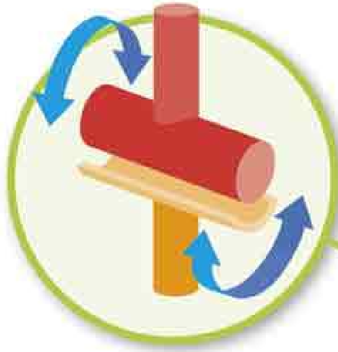
JOINT DESIGNS

Different kinds of joints are named after the shapes of the bones they consist of or the type of movement they allow. Usually, the lesser the range of movement, the stronger and more stable the joint.

Fingers moving beyond range of normal joint

DOUBLE JOINTED

People whose joints can bend much more than normal are sometimes called double jointed. While there is only one joint, the strap-like ligaments that hold the bones together, and the muscles that pull them, are super stretchy and allow extra movement.



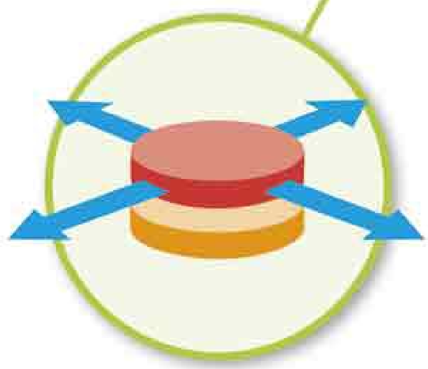
HINGE

Hinge joints in the knees and the finger and toe knuckles, let these bones move backwards and forwards, but they cannot move sideways or twist.

BALL AND SOCKET

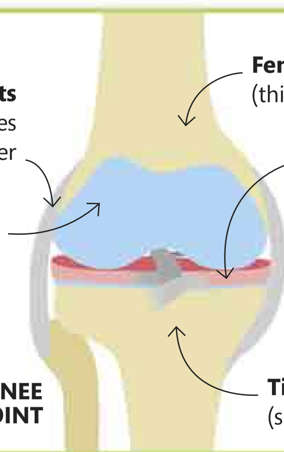
The ball-shaped top of the femur (thighbone) slots into a bowl-like socket in the pelvis (hipbone) to give a wide range of motions – to and fro, sideways, and twisting.

“There are 150 joints that cannot move”



GLIDING

The seven angular, box-shaped ankle bones have little tilting motion. They can slide to and fro as well as sideways against each other.



SHOCK ABSORBERS

In most joints, the areas where the bones meet are covered with cartilage, which is smooth to reduce friction and slightly squashy to absorb pressure. A thin layer of slippery fluid reduces friction even more. The knee has two extra cartilage cushions, each called a meniscus, between the bones for extra steadiness.

Limbering up

Gymnasts increase the range of movement in their joints by carefully exercising the muscles, tendons, and ligaments around them. They learn how to relax the muscles fully so that they can be stretched further.

FLIPPING OUT

Flexibility

There are several reasons for hypermobility — the ability of some joints to bend and twist more than usual. The bone ends might be a slightly different shape, such as flatter rather than bowl-like. Some people naturally produce more collagen — the part of ligaments that holds bones together – than others, which makes their ligaments stretchier. Variations in hormone levels, especially that of the female hormone oestrogen, can also affect ligament strength.

STATS AND FACTS

BACKBONE JOINTS

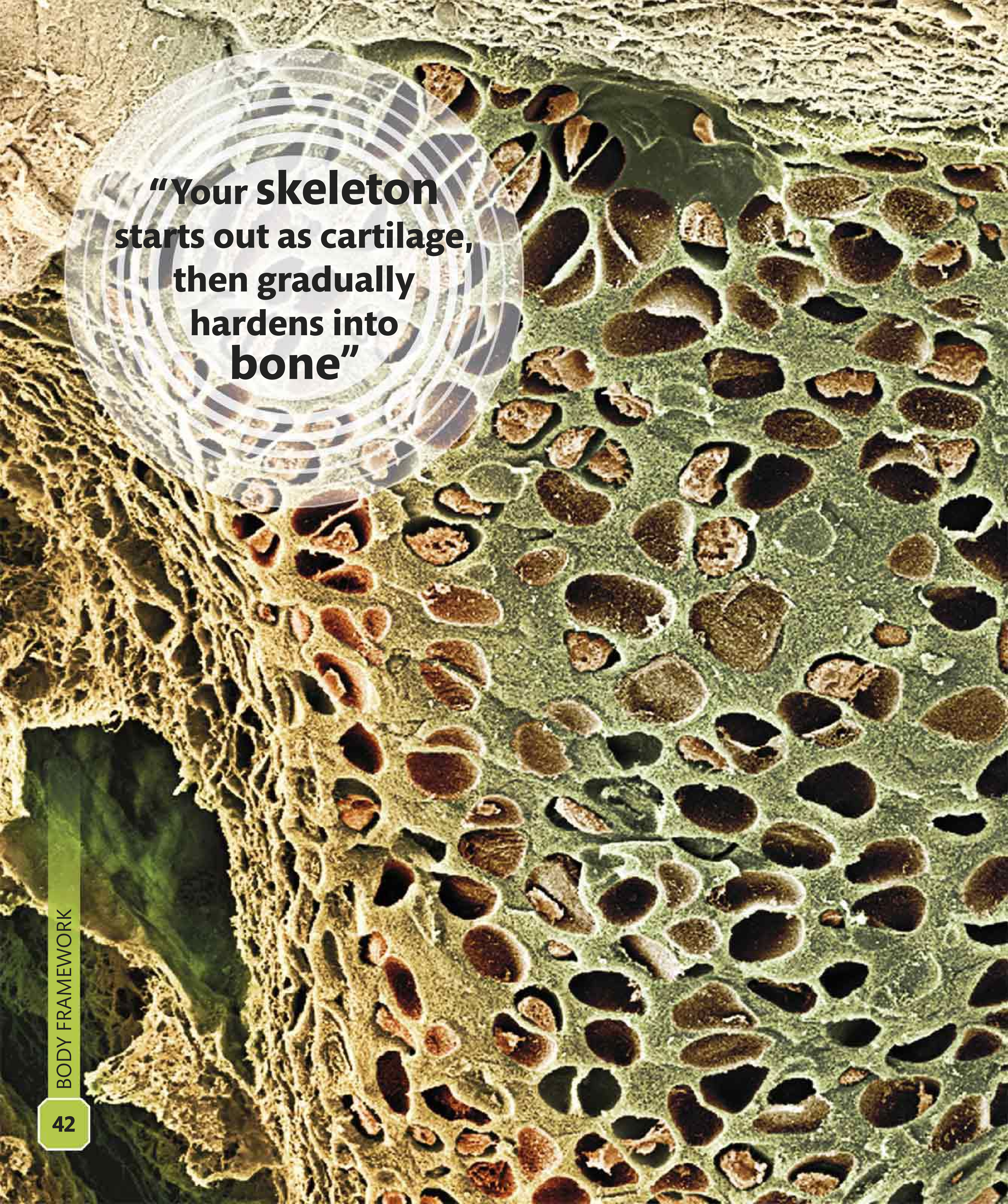
FROG **9** Fewest backbone joints

HUMAN **24** Total number of moveable backbone joints

SLENDER SNIPE EEL **750** Most backbone joints

360° Shoulder can rotate in two directions

“**One** person in **30** has **extra-flexible** joints”



"Your skeleton starts out as cartilage, then gradually hardens into bone"

TOTALLY SMOOTH

Cartilage

Cartilage is one of the body's simplest tissues, but it plays a vital role – it stops the ends of your bones wearing away where they meet at the joints. It has only one type of cell, the chondrocyte. These cells surround themselves with a substance called the cartilage matrix, which contains no nerves, blood vessels, or other tissues. Cartilage is smooth and hard-wearing, yet a bit squashy and slippery. It also forms various stiff-yet-bendy body parts, such as the nose and ear flaps.

STATS AND FACTS

QUALITY

Cartilage is **5–10** TIMES more slippery than ice

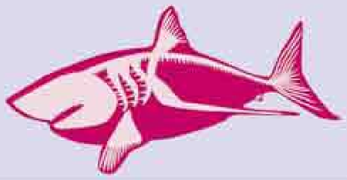
COMPOSITION

Cartilage is up to **80%** water

BODY PERCENTAGES

Cartilage forms **1–2%** of the whole human body

Cartilage makes up **100%** of a shark's skeleton

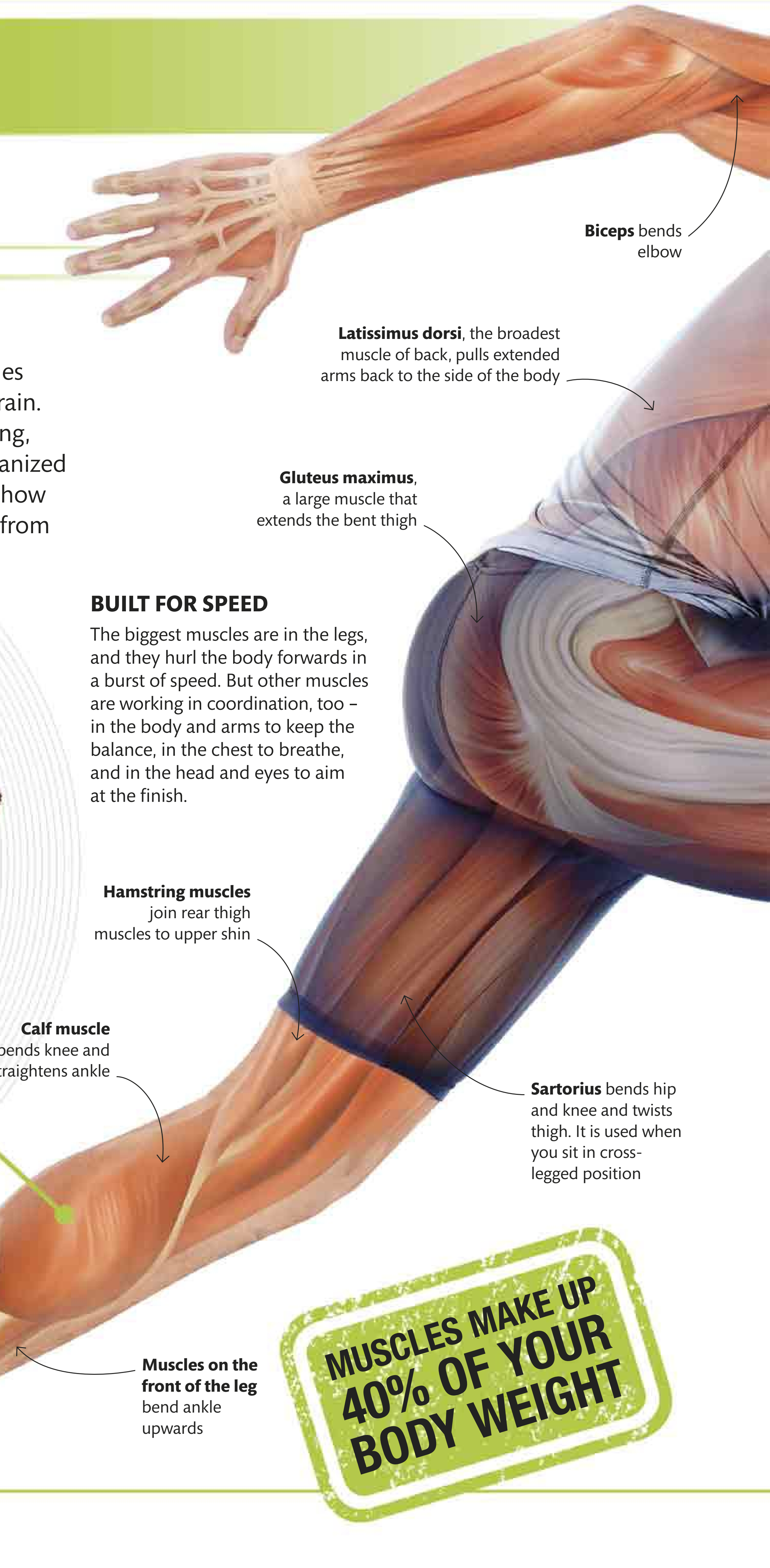


Living in the matrix
Mature chondrocytes (brown) spend their lives in tiny pockets in the cartilage matrix. This matrix is made up of collagen — a component of skin and bone — squishy chondroitin, and stretchy elastin, also found in skin.

FLEX IT!

Muscle power

Muscles account for every movement of the body, from an eye blink to a speeding sprint to a massive power-lift. Each of the hundreds of muscles is precisely controlled by nerve signals from the brain. With practice, common movements such as walking, running, eating, and writing are automatically organized by the relevant parts of the brain. We only realize how complex this control is when we learn a new skill, from threading a needle to snowboarding.



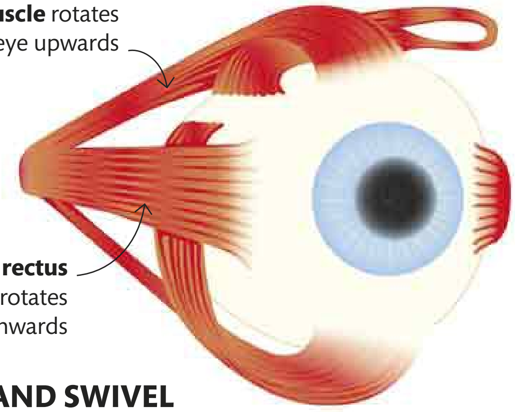
BUILT FOR SPEED

The biggest muscles are in the legs, and they hurl the body forwards in a burst of speed. But other muscles are working in coordination, too – in the body and arms to keep the balance, in the chest to breathe, and in the head and eyes to aim at the finish.

MUSCLE FIBRES

A muscle contains bundles of two kinds of fibres, each 0.1–0.5 mm wide and 5–40 mm (¼–2 in) long. Fast twitch fibres shorten rapidly with great force but tire quickly. Slow twitch fibres contract gradually but keep going for longer.

MUSCLES MAKE UP 40% OF YOUR BODY WEIGHT



SWING AND SWIVEL

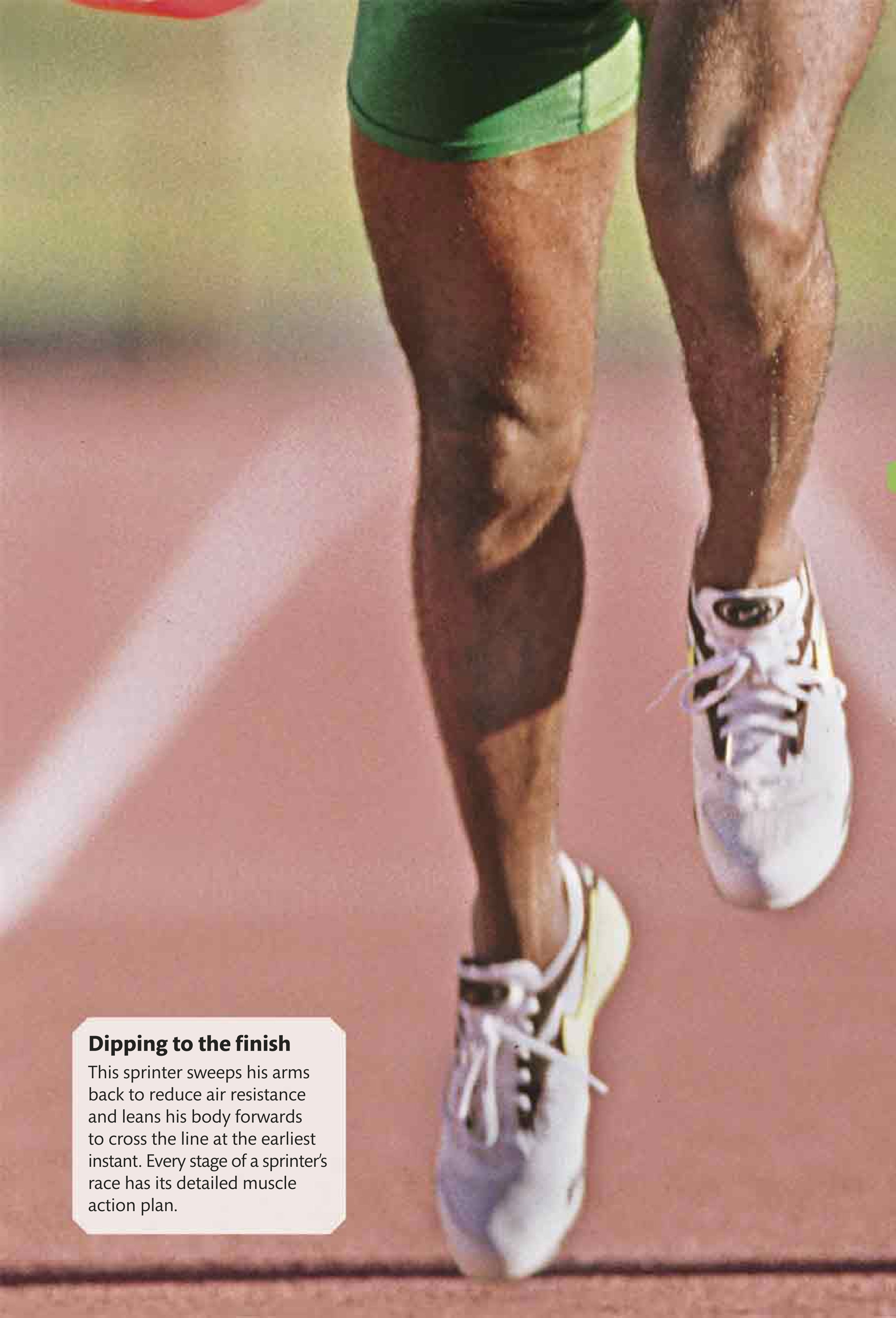
Each eye is moved by six very thin, ribbon-like muscles – the most precise and fastest-acting. One swivels the eye up, another down, the third to the left, the fourth to the right. The other two muscles make fine adjustments, especially when the head moves one way and the eyes swing the other way, to keep the gaze on one object.

“650 skeletal muscles help to shape your body”

HOLDING IT TOGETHER

In most muscles, each end becomes narrower and attaches to a tendon, the other end of which fixes firmly into a bone and passes on the muscle’s pulling force. Bones are held together at joints by ligaments. Many joints have several ligaments to stop the bones from moving too far or coming apart.

"A top sprinter is airborne for 60 per cent of the race"



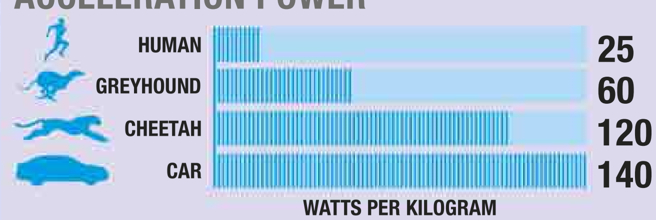
SUPER SPRINTER

Muscles at max

As the hypertuned sprint body blasts into action, more than 600 muscles – in top condition and with precise coordination – work together to propel the body along the track. The gluteus, biceps femoris, and other upper thigh muscles provide most of the forward power, while the deltoids, biceps, triceps, and others pump the arms for added momentum. All the while, the lungs take in more air for extra oxygen. Every detail counts – success is measured in thousandths of a second.

STATS AND FACTS

ACCELERATION POWER



Acceleration power is measured in watts per kilogram (power to weight ratio)

SPRINTING SPEEDS

TOP SPRINTERS MAKE 4.5 STRIDES PER SECOND

FASTEST 100 M SPRINT
9.85
SECONDS

Dipping to the finish

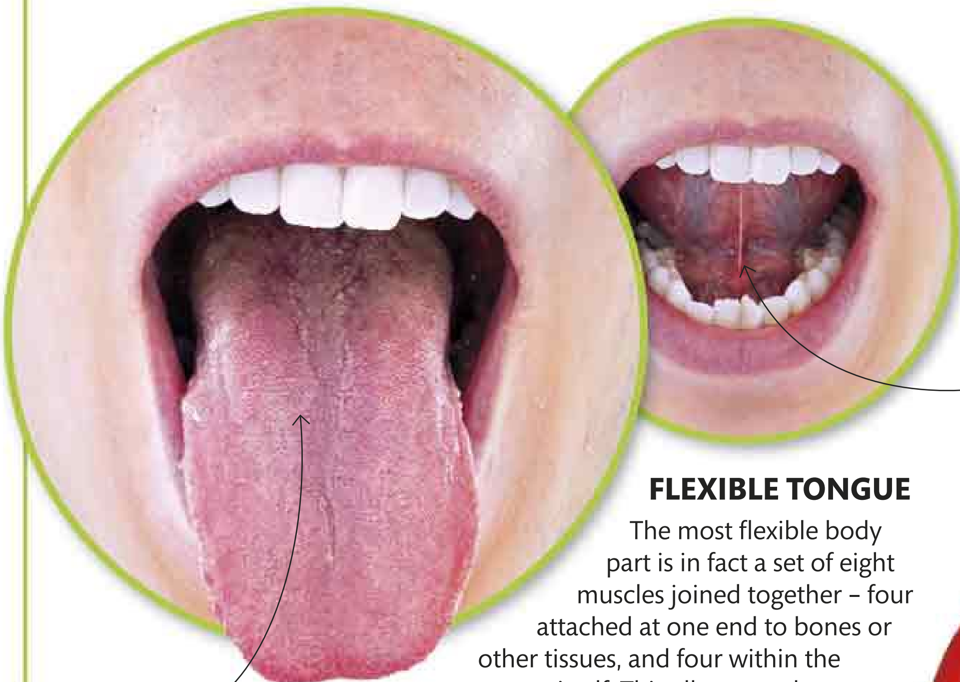
This sprinter sweeps his arms back to reduce air resistance and leans his body forwards to cross the line at the earliest instant. Every stage of a sprinter's race has its detailed muscle action plan.

TEAMWORK

Muscle groups

Muscles rarely work alone. Almost every movement has several muscles, even dozens, acting as a team. A single muscle can only pull or contract – it cannot forcefully push. So muscles are arranged in groups, for example, around a bone. One group pulls the bone one way; another muscle team pulls the bone another way, another twists it, and so on. So even a seemingly simple movement is an amazing feat of multi-coordination.

EXERCISE MAKES MUSCLES THICKER

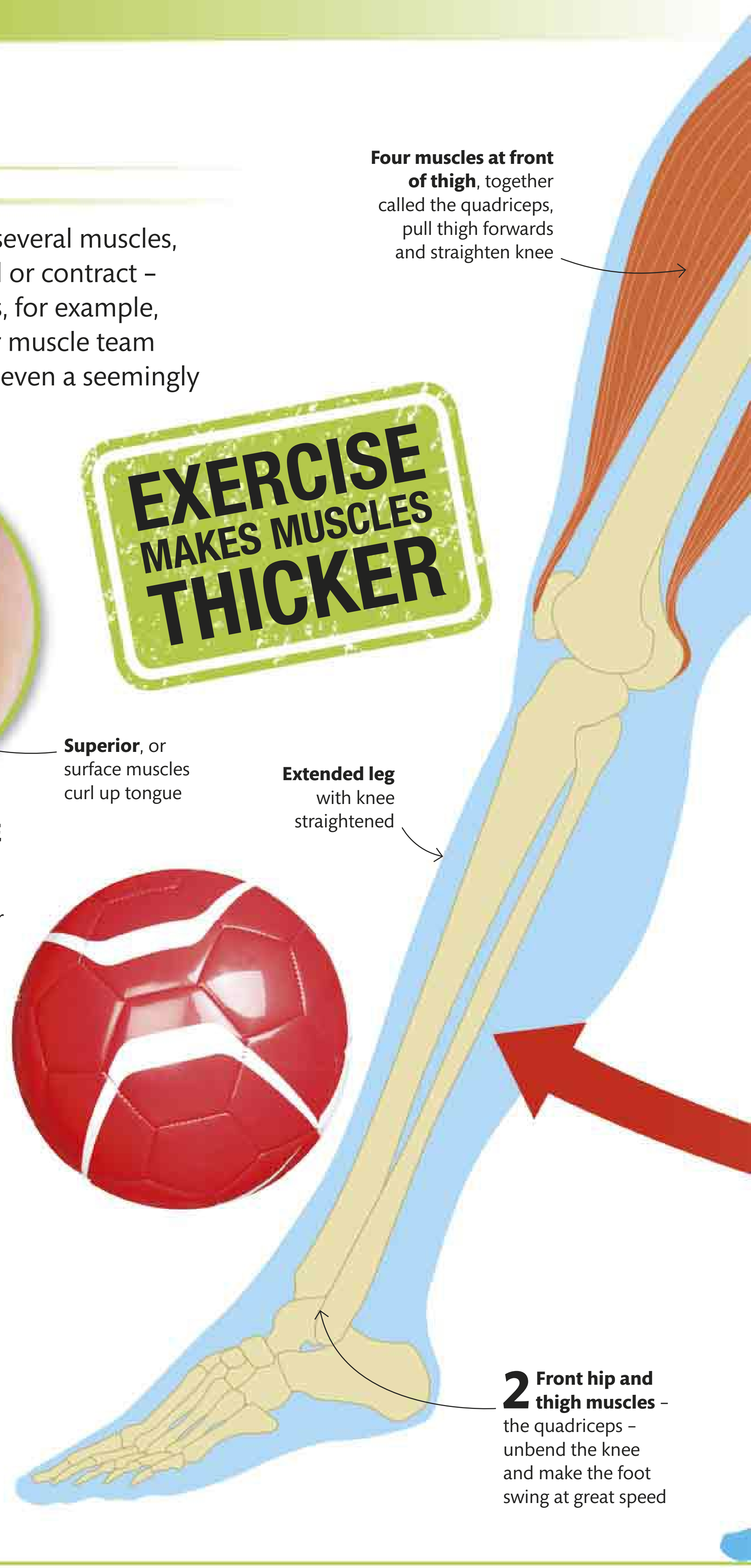


Crossways muscles poke tongue out

Superior, or surface muscles curl up tongue

FLEXIBLE TONGUE

The most flexible body part is in fact a set of eight muscles joined together – four attached at one end to bones or other tissues, and four within the tongue itself. This allows an almost endless range of shapes and movements.

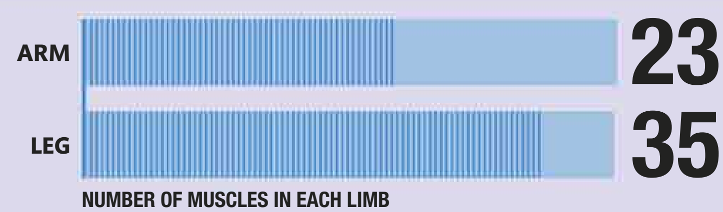


Four muscles at front of thigh, together called the quadriceps, pull thigh forwards and straighten knee

Extended leg with knee straightened

2 Front hip and thigh muscles – the quadriceps – unbend the knee and make the foot swing at great speed

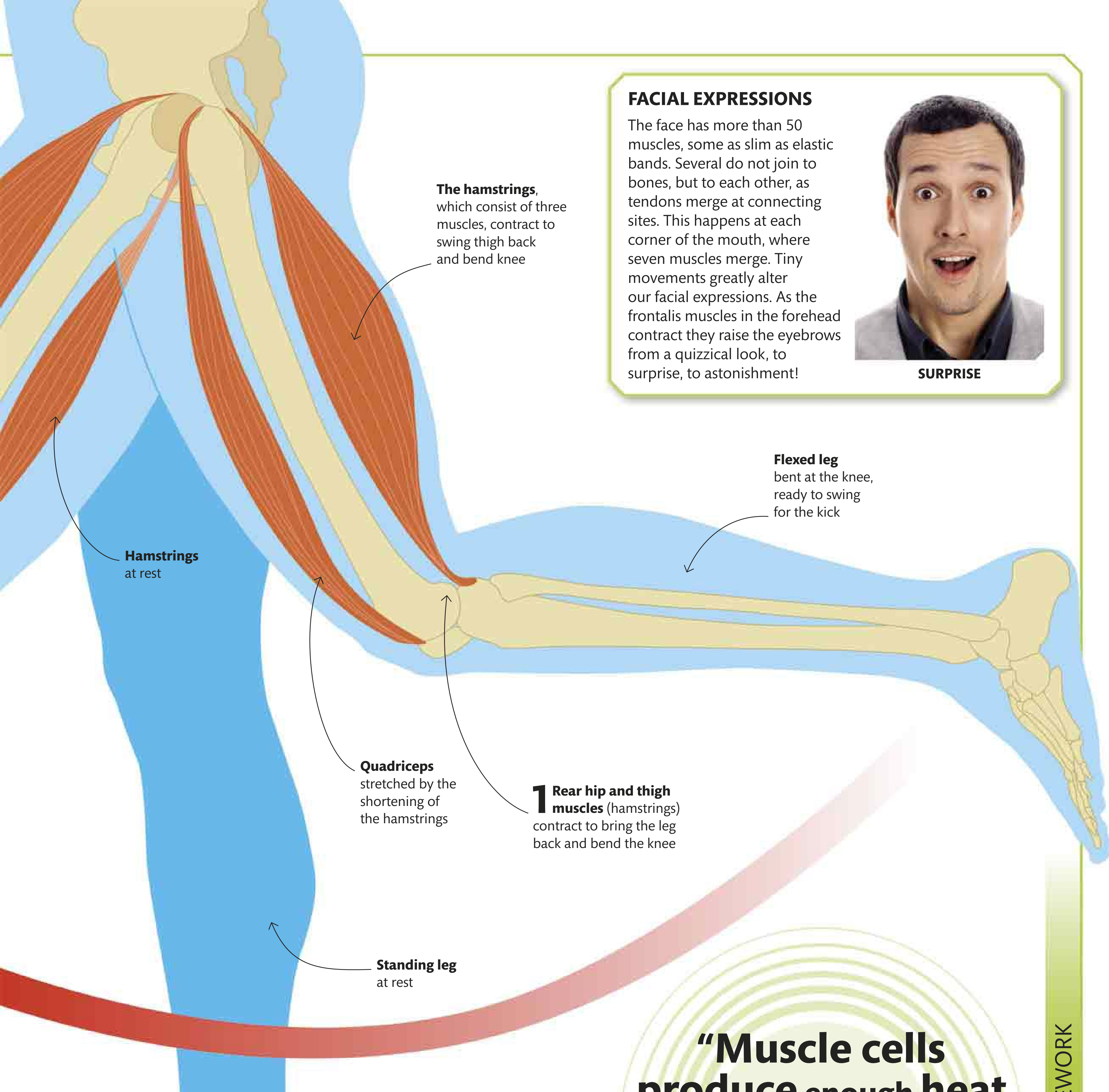
STATS AND FACTS



MUSCLE COORDINATION

You use **8 muscles** (4 pairs) to chew food

You use **35 muscles** to hold a pen



FACIAL EXPRESSIONS

The face has more than 50 muscles, some as slim as elastic bands. Several do not join to bones, but to each other, as tendons merge at connecting sites. This happens at each corner of the mouth, where seven muscles merge. Tiny movements greatly alter our facial expressions. As the frontalis muscles in the forehead contract they raise the eyebrows from a quizzical look, to surprise, to astonishment!

SURPRISE

MUSCLES IN ACTION

The hip and thigh have the bulkiest, strongest muscles to move the leg to and fro. For a kick, muscles at the front pull fast and hard to swing the thigh forwards at the hip and straighten the knee for a double-action power-hit.

"Muscle cells produce enough heat every day to boil almost 1 litre (2 pints) of water for an hour"

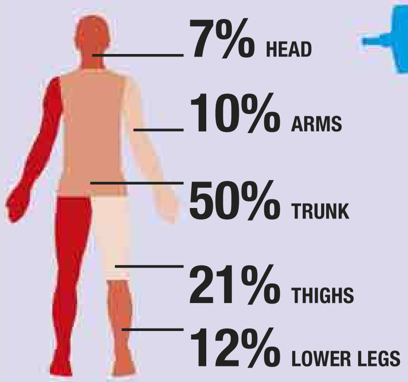
SUPER STRENGTH

Holding power

You don't need to move your muscles to make them work hard – simply tightening them up can produce a huge amount of force. Holding a position requires raw strength. But attention to balance and posture is also important, because it prevents individual muscles wasting energy by having to work against other muscles that are pulling the body out of alignment. With just a slight change in the position of his legs, this gymnast can reduce the power needed by his arm muscles by almost one-seventh.

STATS AND FACTS

WEIGHT DISTRIBUTION



LIFTING CAPACITY

Hanging around
Gymnastic rings are an ultimate test of upper body strength – about a quarter of muscle bulk is in the shoulders, arms, and hands. To hold a position, some muscle groups contract while others relax, then swap over.

"All the body's muscles pulling in one direction would produce a force of 20 tonnes (22 tons)"


2

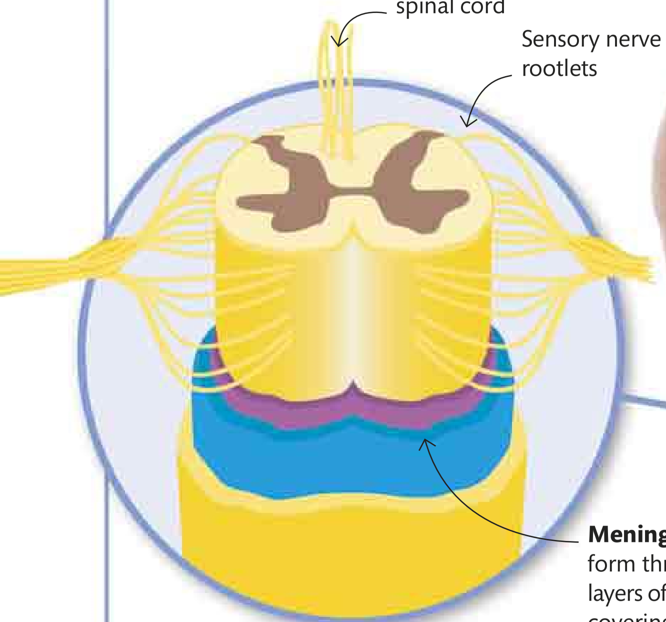
MISSION CONTROL

From its prime position at the top of the body, the all-knowing superbrain is aware of what happens outside the body – and inside, too. Every second, millions of messages carry never-ending thoughts, feelings, memories, and emotions.

TOTAL INTRANET

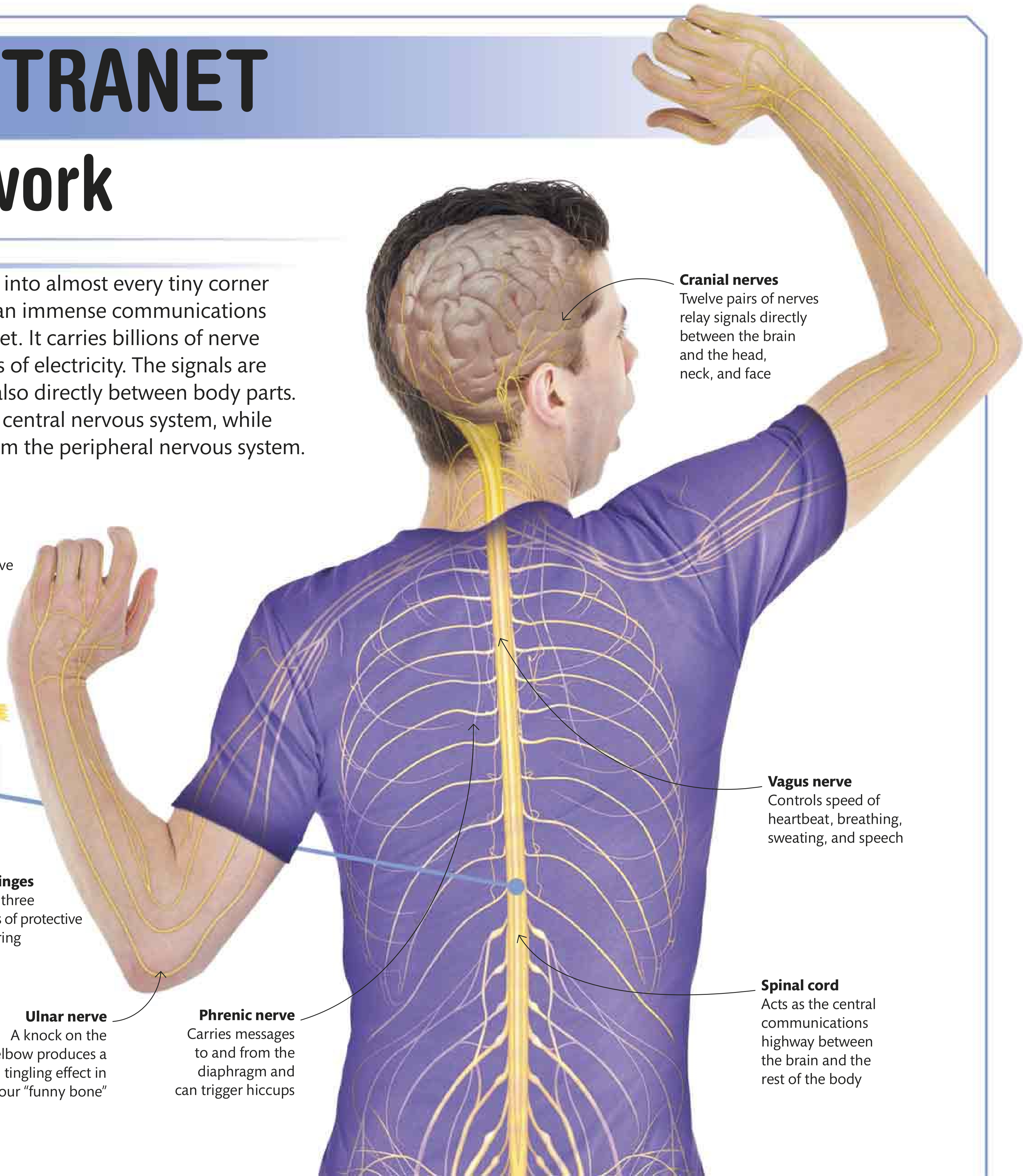
Nerve network

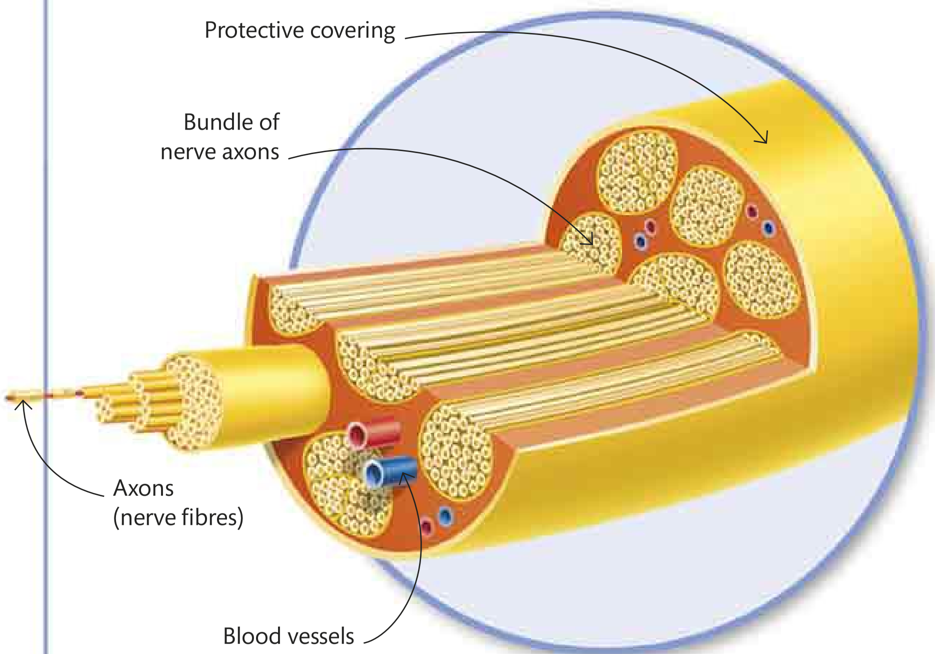
With spidery branches extending into almost every tiny corner of the body, the nervous system is an immense communications network – your own internal internet. It carries billions of nerve signals every second as micropulses of electricity. The signals are flashed to and from the brain and also directly between body parts. The brain and spinal cord form the central nervous system, while the bodywide branching nerves form the peripheral nervous system.



BRAIN–BODY HIGHWAY

The spinal cord is the brain's major link with the rest of the body. Although it is only as wide as a little finger, it contains more than 20 million nerve fibres. From it extend 31 pairs of spinal nerves to the chest, arms, lower body, and legs.





WHAT A NERVE!

A typical nerve contains thousands of nerve fibres, or axons, wrapped into bundles called fascicles. The whole nerve is contained within a tough, flexible covering that protects the fibres as the body parts around the nerve move, bend, squash, and pull at it.

STATS AND FACTS

AVERAGE LENGTH OF SPINAL CORD

HUMAN	44 cm (17 in)
CAT	34 cm (13 in)
RABBIT	18 cm (7 in)

350 km/h (217 mph) The rate at which the fastest nerves in your body carry signals

2 cm (¾ in) The width of the thickest nerve – the sciatic nerve

Adult brains lose 100,000 neurons per day

THERE ARE 60 KM (37 MILES) OF NERVES IN THE HUMAN BODY

HEAD TO TOE

Nerves stretch throughout your body like electricity cables, branching and dividing to reach every part. The distance from the brain to the toe can be more than 1.8 m (6 ft) in an adult, yet messages can travel between the two in $^{1}/_{100}$ of a second.

Split-second decisions

To perform a steep turn, a pilot has to multitask: lower the left hand to descend, feel the nose dip, move the right hand sideways and right foot down, watch the horizon, and monitor balance – all in one second!

"The brain can handle 1 billion billion nerve messages per second"

FLYING HIGH

Multitasking

Action situations put the brain into a state of high alert – turning it into a living supercomputer. Millions of messages, flooding in from all the senses, are sorted and filtered in different parts of the brain, but you only become aware of the most vital pieces of information. Hundreds of decisions, some conscious but many automatic, fire thousands of instructions every second to dozens of body muscles, to produce coordinated reactions to each situation.

STATS AND FACTS

COUNTDOWN TO A COLLISION

TIMELINE TO AVOID MIDAIR COLLISION

0.1 sec	SEE OBJECT
1.0 sec	RECOGNIZE OBJECT
5.0 sec	BECOME AWARE OF POTENTIAL COLLISION
4.0 sec	DECISION TO TURN OR CLIMB
0.4 sec	MUSCULAR REACTION
2.0 sec	AIRCRAFT RESPONSE TIME
12.5 sec	TOTAL

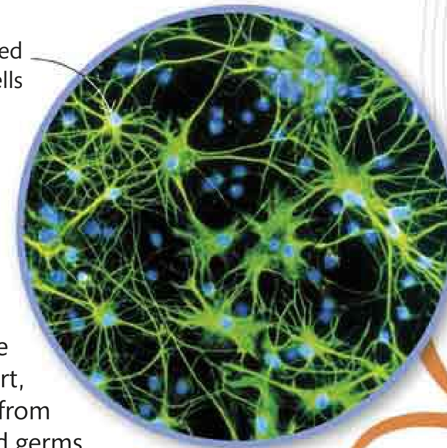
90 minutes

Maximum time the brain can concentrate on something before losing efficiency

INSIDE THE MEGAWEB

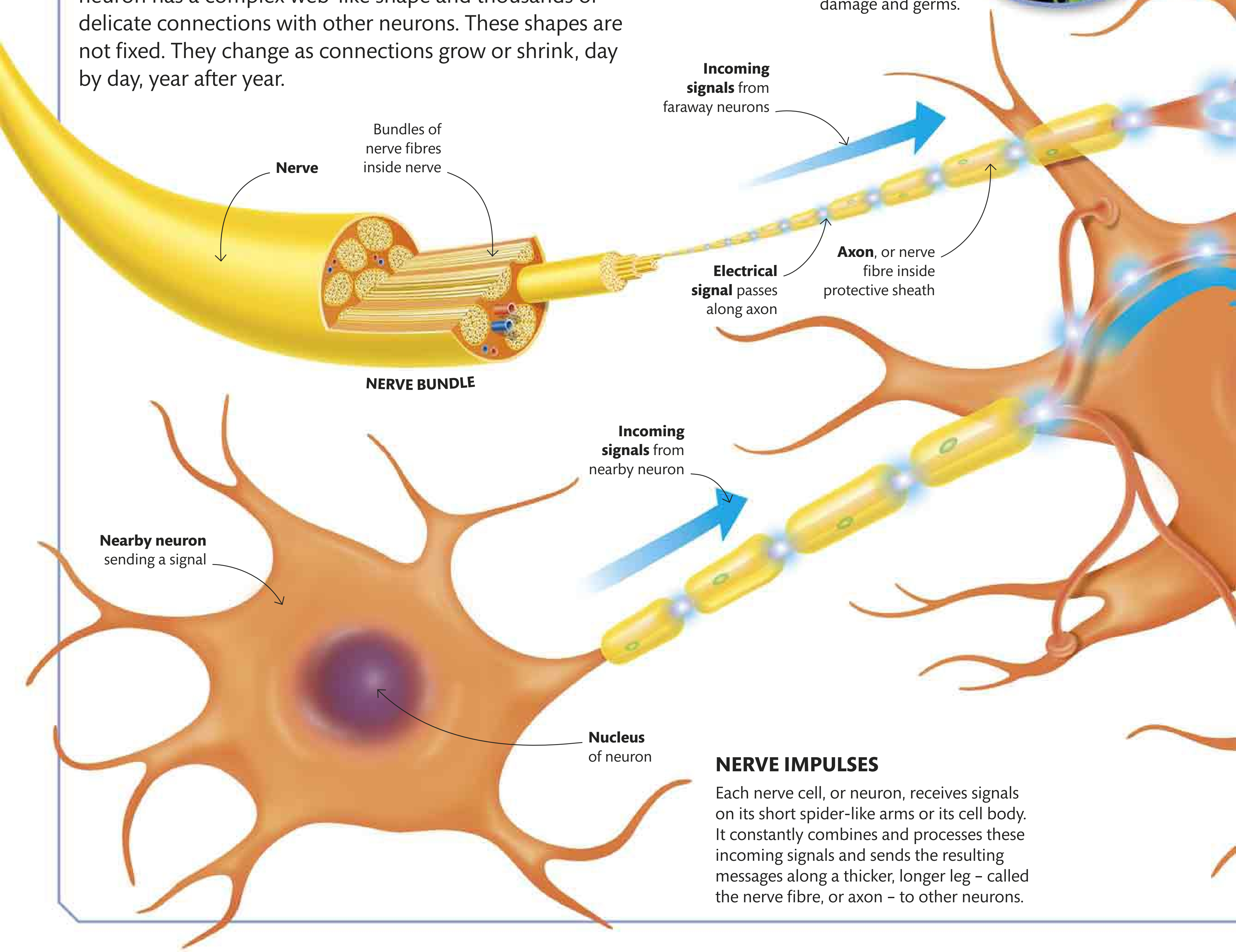
Nerves and nerve cells

Take apart the nerve system, bit by bit, and you reach its smallest parts – nerve cells, or neurons. They are among the most specialized and long-lasting of all cells. Their job is to receive, process, and send on nerve messages, in the form of tiny pulses of electricity. Each neuron has a complex web-like shape and thousands of delicate connections with other neurons. These shapes are not fixed. They change as connections grow or shrink, day by day, year after year.



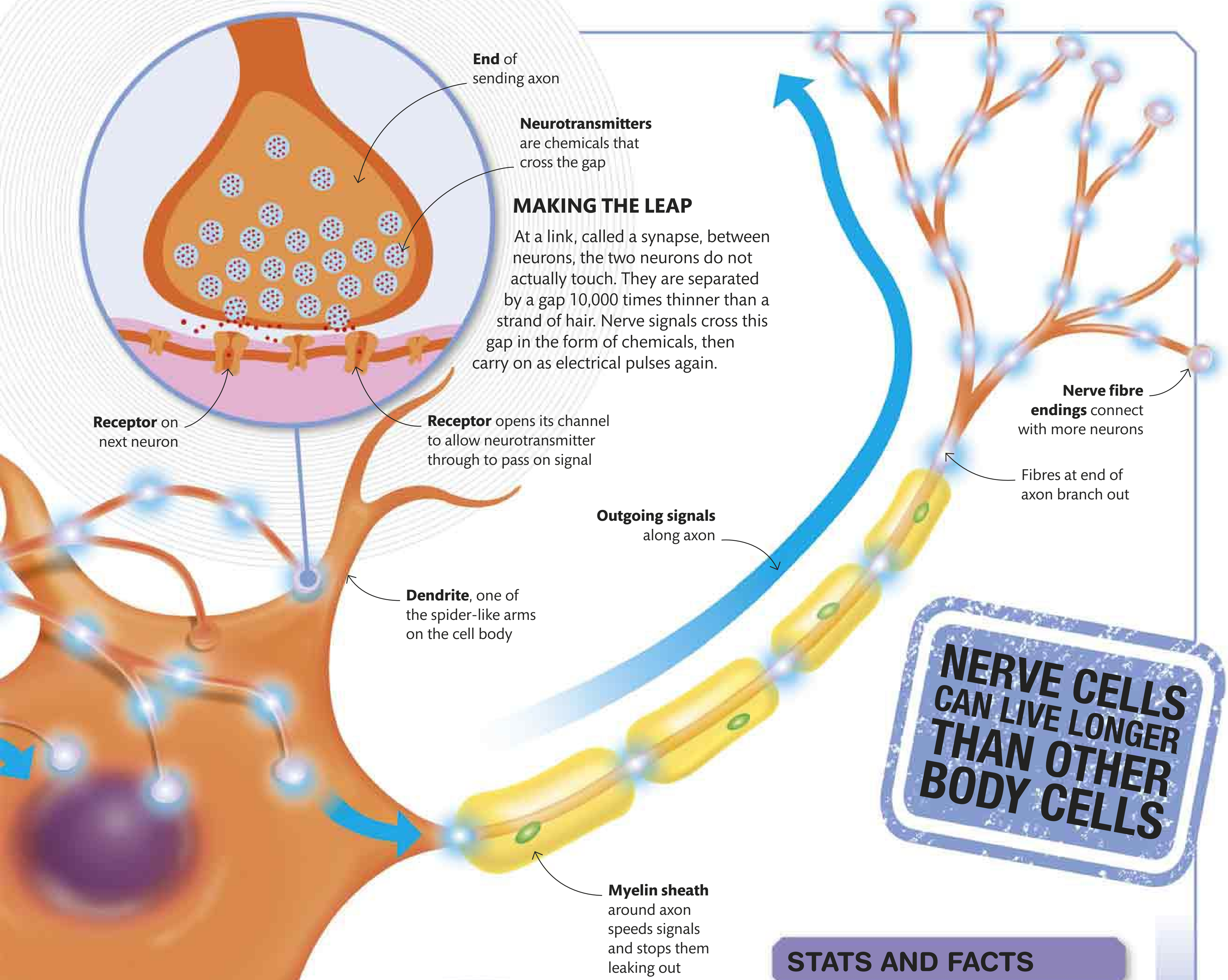
LITTLE HELPERS

In the entire nerve system, fewer than half the cells are neurons. The rest – called glial cells – give neurons physical support, nutrients, and protection from damage and germs.



NERVE IMPULSES

Each nerve cell, or neuron, receives signals on its short spider-like arms or its cell body. It constantly combines and processes these incoming signals and sends the resulting messages along a thicker, longer leg – called the nerve fibre, or axon – to other neurons.



MAKING THE LEAP

At a link, called a synapse, between neurons, the two neurons do not actually touch. They are separated by a gap 10,000 times thinner than a strand of hair. Nerve signals cross this gap in the form of chemicals, then carry on as electrical pulses again.

NERVE CELLS CAN LIVE LONGER THAN OTHER BODY CELLS

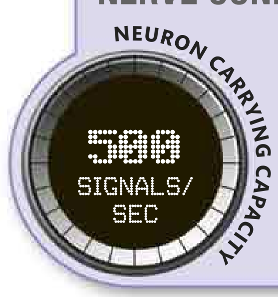
"If you were a neuron you would have 10,000 arms"

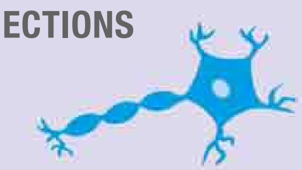
STATS AND FACTS

SURFACE AREA OF ALL NEURONS IN BRAIN

4 x SOCCER PITCH

NERVE CONNECTIONS

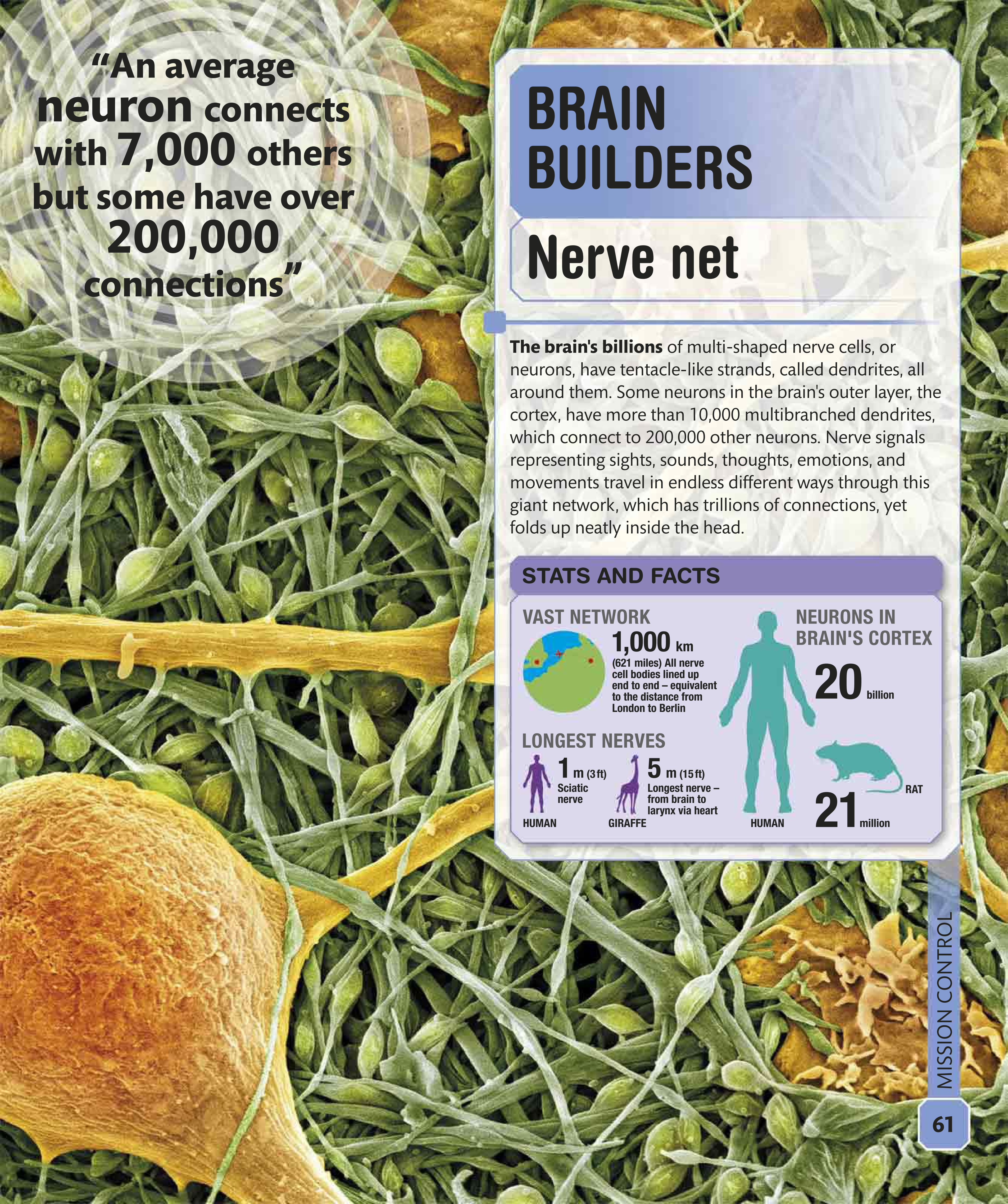




500 trillion
The number of connections in the nervous system

Talking to friends

Shown here at almost 10,000 times their size, the axons and dendrites of neurons (in green) reach out to connect with each other. The glial cells (in orange) provide them with structural support and protection.



"An average **neuron** connects with **7,000** others but some have over **200,000** connections"

BRAIN BUILDERS

Nerve net

The brain's billions of multi-shaped nerve cells, or neurons, have tentacle-like strands, called dendrites, all around them. Some neurons in the brain's outer layer, the cortex, have more than 10,000 multibranched dendrites, which connect to 200,000 other neurons. Nerve signals representing sights, sounds, thoughts, emotions, and movements travel in endless different ways through this giant network, which has trillions of connections, yet folds up neatly inside the head.

STATS AND FACTS

VAST NETWORK

1,000 km

(621 miles) All nerve cell bodies lined up end to end – equivalent to the distance from London to Berlin

LONGEST NERVES

1 m (3 ft) Sciatic nerve

HUMAN

5 m (15 ft) Longest nerve – from brain to larynx via heart

GIRAFFE

NEURONS IN BRAIN'S CORTEX

HUMAN **20** billion

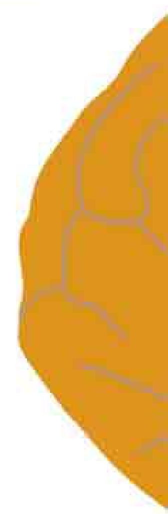
RAT **21** million

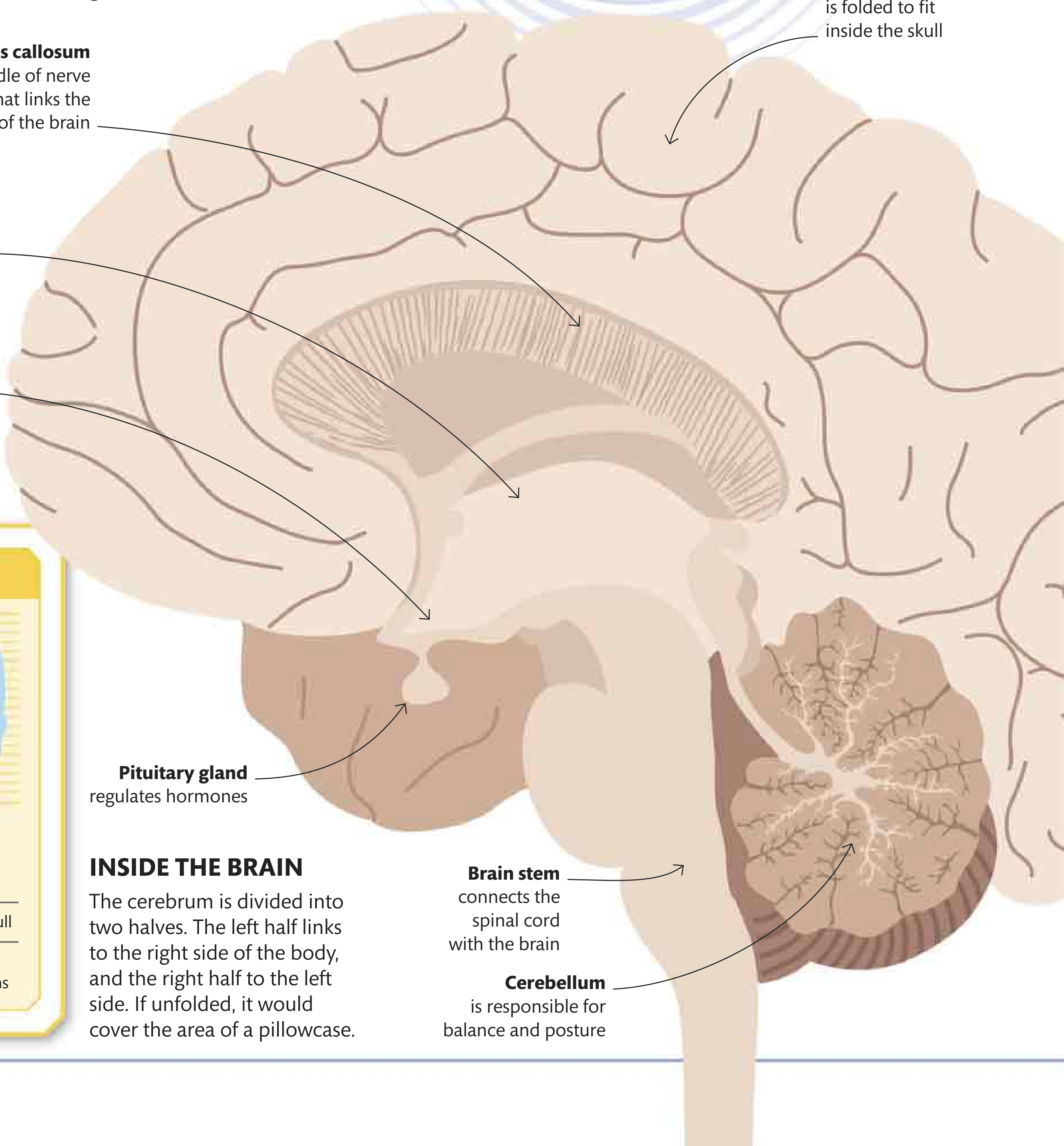
PROCESSING POWER

The brain

Soft, pale, wrinkly, and unmoving, the brain doesn't look very impressive. Yet it controls almost every move the body makes and is the site of our thoughts, feelings, and memories. As it is so essential to us, it is well protected inside the skull's hard dome, surrounded by cushioning fluids and layers of tissue called meninges. Its biggest part, taking up three-quarters of its bulk, is the cerebrum whose surface is covered with grooves and bulges.

"The brain is a million times more efficient than a computer of a similar size"



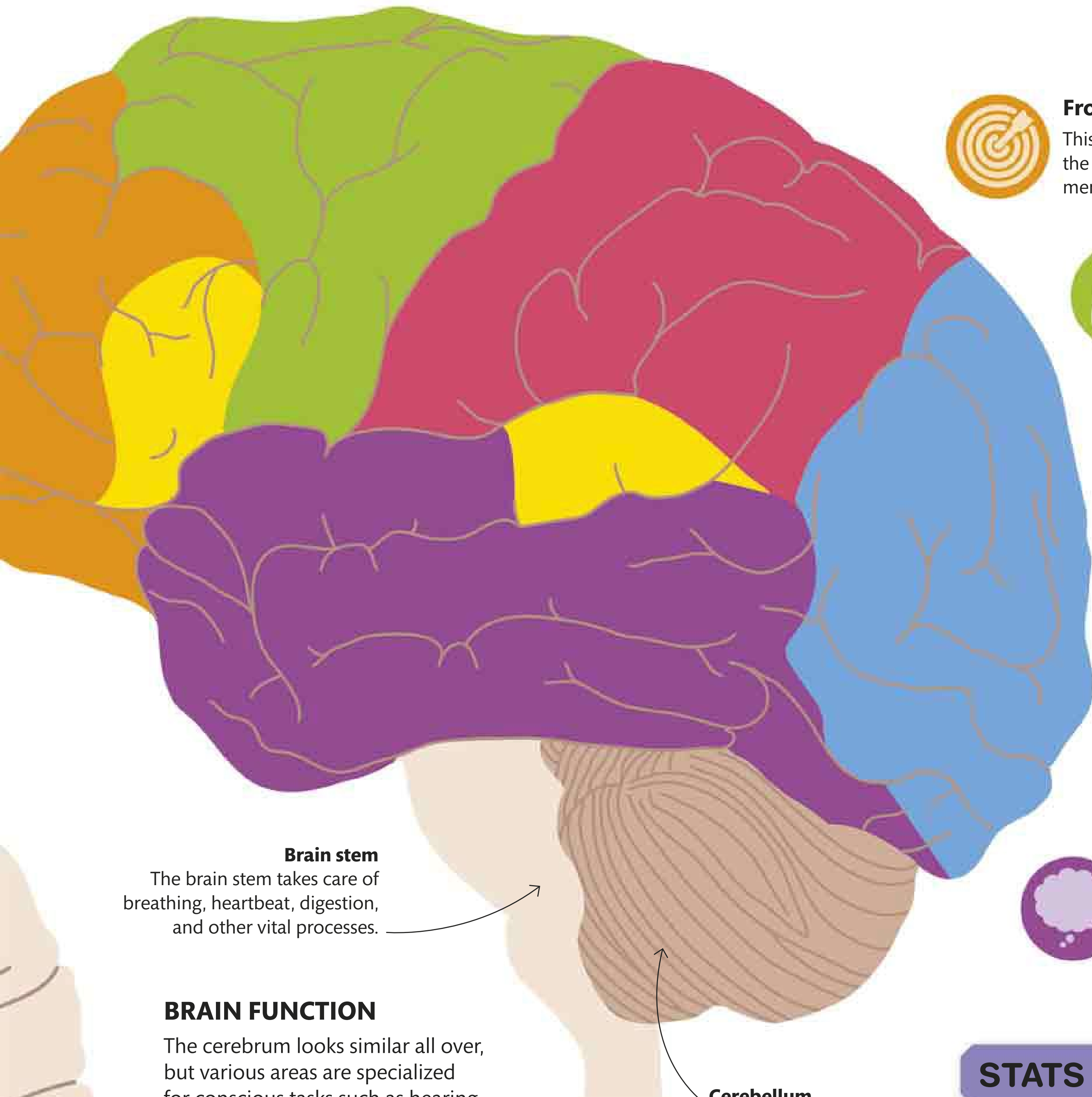


AT A GLANCE

- **SIZE** Average adult brain: weight 1.4 kg (3 lb); width 14 cm (6 in); length 17 cm (7 in); height 9.5 cm (4 in)
- **LOCATION** Almost fills the top half of the skull
- **FUNCTION** Gets data, takes decisions, stores memories, controls movements and emotions

INSIDE THE BRAIN

The cerebrum is divided into two halves. The left half links to the right side of the body, and the right half to the left side. If unfolded, it would cover the area of a pillowcase.



Front area
This region is involved with the tasks of planning, reason, memories, and personality.

Motor area
Controls and coordinates muscle movements.

Sensory area
Deals with touch sensations from the skin, mouth, and tongue.

Sight area
The back of the brain handles vision and makes sense of what you see.

Speech and hearing areas
These control speaking, hearing, and understanding words.

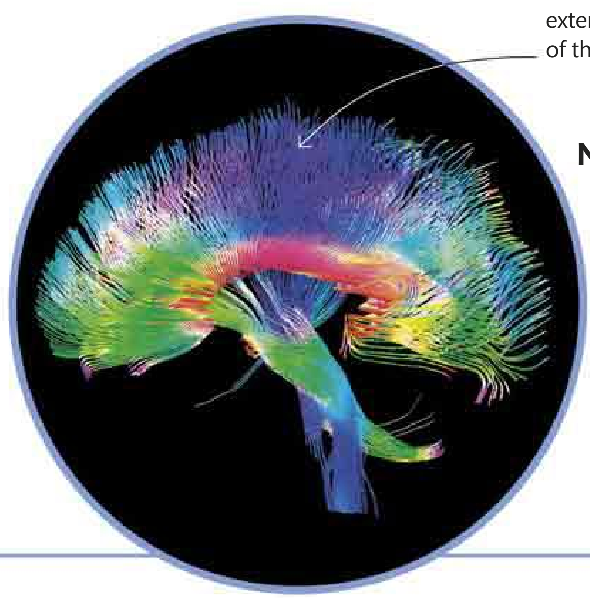
Lower side lobes
This area deals with memory, information retrieval, and emotions.

Brain stem
The brain stem takes care of breathing, heartbeat, digestion, and other vital processes.

Cerebellum
The cerebellum ensures that movements are smoothly coordinated.

BRAIN FUNCTION

The cerebrum looks similar all over, but various areas are specialized for conscious tasks such as hearing, speech, movement, touch, and sight. The lower parts of the brain control more basic, automatic life processes, such as breathing.



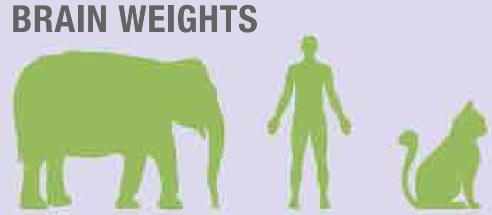
Nerve pathways extend to all areas of the brain

NERVE TRACTS

This scan shows how bundles of nerve fibres spread from the lower brain to all parts of the cerebrum. They then branch out into billions of individual nerve cells that control everything you do.

STATS AND FACTS

BRAIN WEIGHTS



4,500 g (10 lb)

1,400 g (3 lb)

30 g (1 oz)

20% of body energy is used up by the brain

2% of body weight is made up by the brain

LIVING DANGEROUSLY

The teen brain

On the outside, the brain looks similar all through life. But its trillions of micro-connections are constantly changing, especially in the early years. Some parts of the brain develop faster than others. The parts that seek new thrills and exciting events develop faster than those that think through situations and avoid danger. The teenage years are a time when this mismatched development may affect the brain's natural balance for a while, until care and common sense take over again.

STATS AND FACTS

NEURONS IN THE BRAIN

CHIMP	7 BILLION
ELEPHANT	23 BILLION
HUMAN	100 BILLION

LIGHT-BULB MOMENT

10–20 WATTS

The power produced by a brain – enough to light up a low-energy bulb

PROPORTION OF FAT IN BRAIN

50 PER CENT

Defying gravity

Suspended in midair, arms thrown to his side, this young stunt biker throws caution to the wind. As different parts of the brain develop with age, we tend to make safer choices rather than take risks.

“Older teenagers are almost twice as likely to take risks than anyone else”

ACTION STATIONS

Making moves

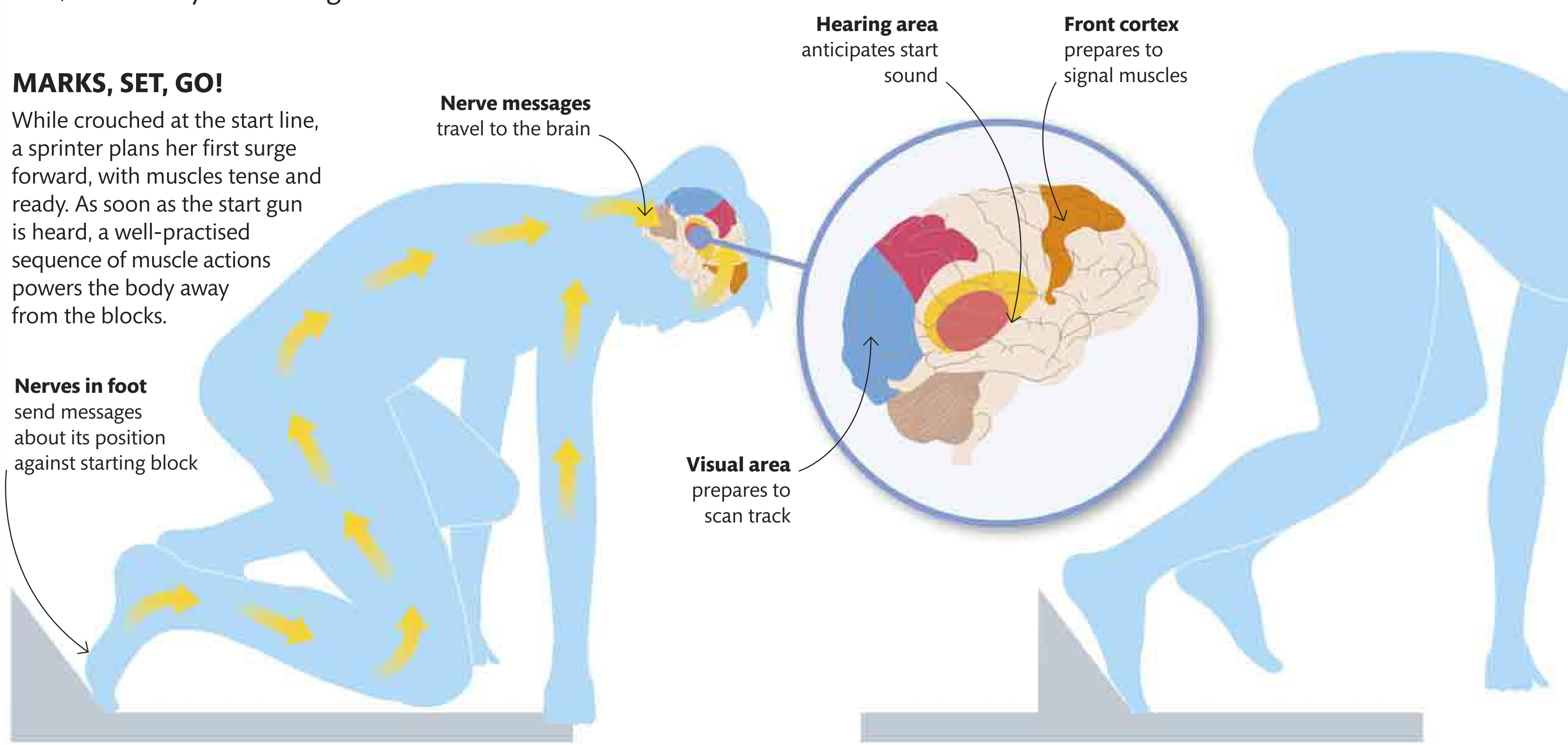
Some body movements, such as heartbeats and breathing, happen day and night. These internal actions are mostly involuntary, or controlled by automatic parts of the brain, so the conscious mind does not need to think about them. Voluntary movements are controlled by the conscious mind's decisions. Their instructions begin as thousands of nerve messages in the motor area at the top of the brain. The messages speed to other brain parts, especially the small, wrinkled cerebellum at the lower rear, and finally race along nerves to the muscles.

CONCENTRATION

The brain's awareness can focus entirely on one movement or motor task, such as playing an instrument. Closing the eyes shuts off sight, and various brain parts, such as the thalamus, filter out other unwanted nerve signals.

MARKS, SET, GO!

While crouched at the start line, a sprinter plans her first surge forward, with muscles tense and ready. As soon as the start gun is heard, a well-practised sequence of muscle actions powers the body away from the blocks.



READY

Feedback signals to the brain from muscles, skin, and joints report on position and readiness of limb muscles.

- Hearing area of brain anticipates signal to rise
- Muscles are tense and ready
- Front cortex prepares movement plan

SET

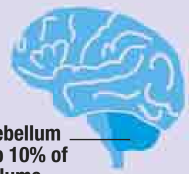
The brain orders the leg muscles partly to extend the hip and knee joints, as the feet brace against the starting blocks.

- Hearing area of the brain detects voice command
- Premotor area of the brain plans the action
- Thalamus works with premotor area

STATS AND FACTS

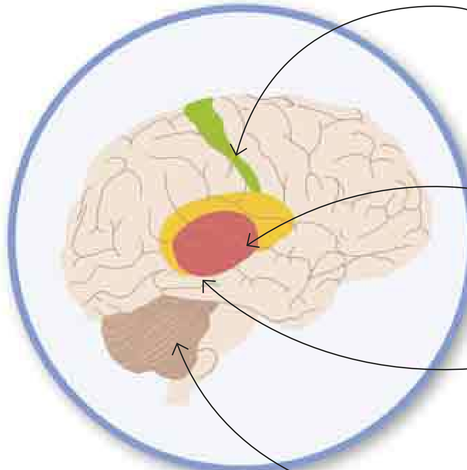
347 days
The time it would take to walk around the world non-stop, at an average speed of 5 km/h (3 mph)

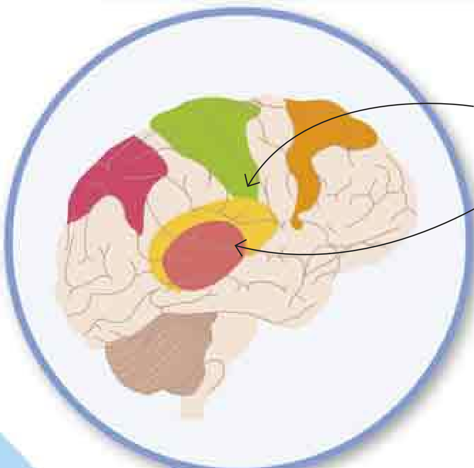
0.1 seconds
The shortest time between hearing start gun and leaving block

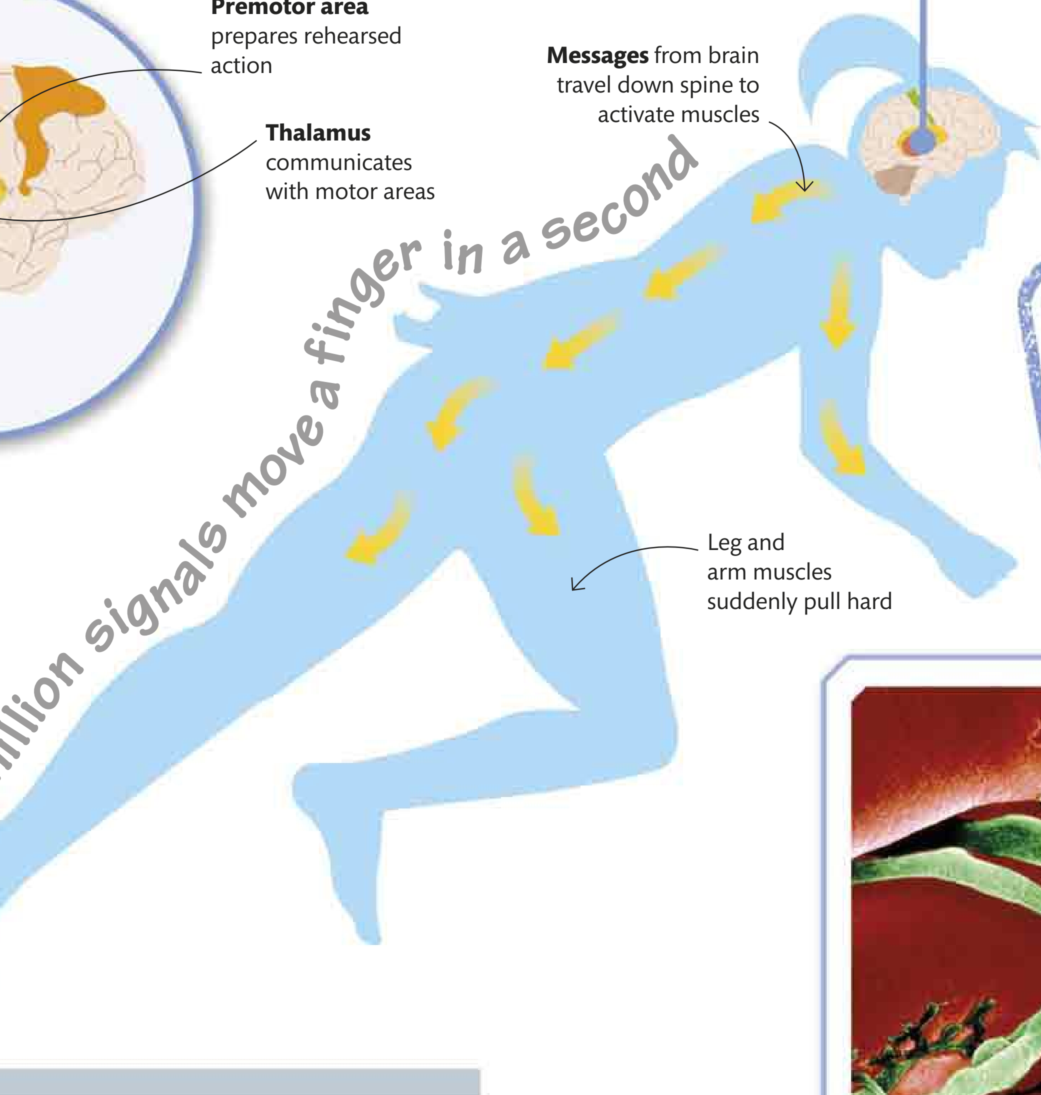


The cerebellum takes up 10% of brain volume

The cerebellum has **50%** of brain neurons





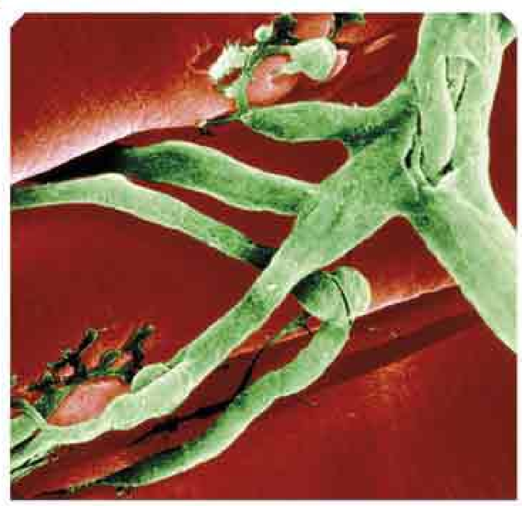


THE CEREBELLUM HAS 85 BILLION NEURONS

GO

Leg muscles push hard to drive the body forwards, with the "quick" (front) leg providing most thrust.

- Hearing area of the brain senses start sound
- Motor area of the brain takes overall control
- Cerebellum provides coordination



NERVE JUNCTION

Movement, or motor, messages pass along nerves (green) to the muscles they control. Each nerve fibre has a motor end plate where the electrical nerve signals pass into muscle fibres (red), telling them to shorten.

LIGHTNING STRIKE

Fast reactions

The human body can react to a sudden sensation with incredible speed and produce a forceful move, such as a push or a kick, in just one-fifth of a second. Smaller movements are even faster, with a blink lasting a tenth of a second. But even with practice, there are limits to reaction times. For nerve signals to go from eye to brain and then be processed takes about one-twentieth of a second, while nerve messages from brain to foot muscles may take almost one-thirtieth of a second.

STATS AND FACTS

REACTION TIMES

Fastest punch, start to finish
0.2 sec

Kick reaction speed
35 m/sec
(over 115 ft/sec)

RESPONSE TO STIMULUS

SOUND **0.14** sec

SIGHT **0.18** sec

80%
Improved reaction time after practice

"Reaction times become slower with a lack of sleep"

Capoeira acrobatics

Dance, music, and martial arts come together in capoeira. A combined game, sport, and competition from Brazil, it demands extreme speed in reactions and moves, such as kicks and leg sweeps.

LOOK OUT!

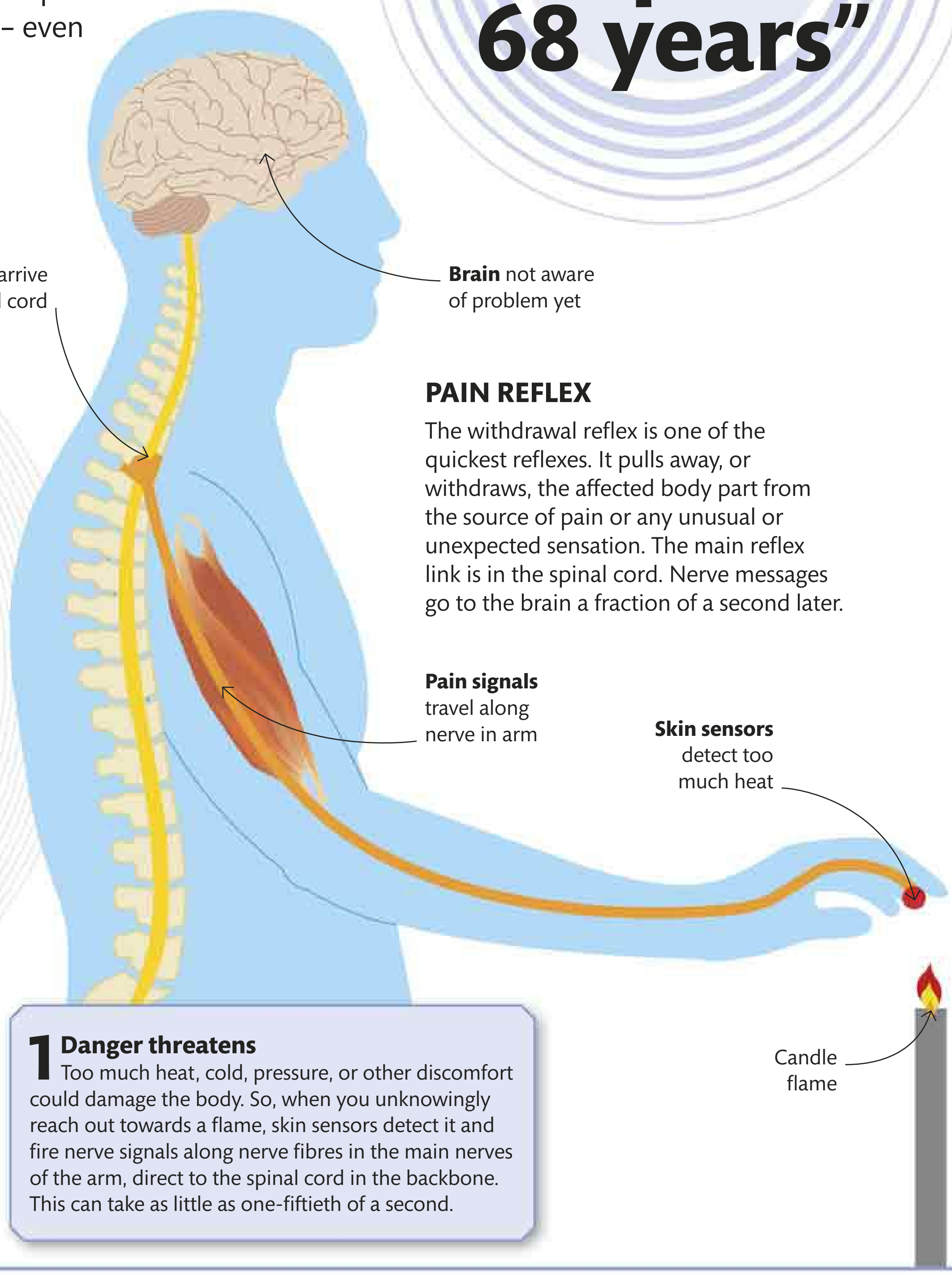
Reflex actions

Sometimes parts of the body move by themselves, without the thinking brain telling them. For instance, your eyes blink every few seconds. A tickly nose causes a sudden sneeze, while a sore throat prompts a cough. A loud noise makes you look around. Any feeling of pain triggers rapid action to stop it. These kinds of automatic actions are known as reflexes. They happen superfast and help the body to stay safe and healthy – even when the brain is busy concentrating on something else. Only after the reflex action does the brain become aware of what has actually happened.

"The longest attack of hiccups lasted 68 years"

BORED? TIRED? YAWN...

Yawns occur when tired, bored, stressed, worried – or when someone else yawns! There are many ideas about why we yawn, from getting more oxygen into the blood, or carbon dioxide out, to stretching face and throat muscles, even cooling the brain. But no one really knows.



PAIN REFLEX

The withdrawal reflex is one of the quickest reflexes. It pulls away, or withdraws, the affected body part from the source of pain or any unusual or unexpected sensation. The main reflex link is in the spinal cord. Nerve messages go to the brain a fraction of a second later.

1 Danger threatens
Too much heat, cold, pressure, or other discomfort could damage the body. So, when you unknowingly reach out towards a flame, skin sensors detect it and fire nerve signals along nerve fibres in the main nerves of the arm, direct to the spinal cord in the backbone. This can take as little as one-fiftieth of a second.

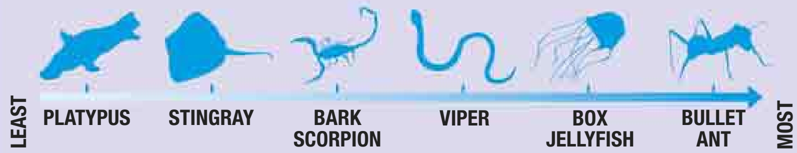
TYPES OF REFLEXES

Healthy reflexes show the nerve system is working well, so they are regularly tested at medical check-ups. The pupil reflex is the busiest. As the eye looks around at light and dark areas, a reflex link to the iris muscles (coloured part) continuously adjusts the size of the pupil (hole), to keep the amount of light passing through the same. Another test is the knee jerk, when tapping just below the kneecap makes the lower leg kick up.

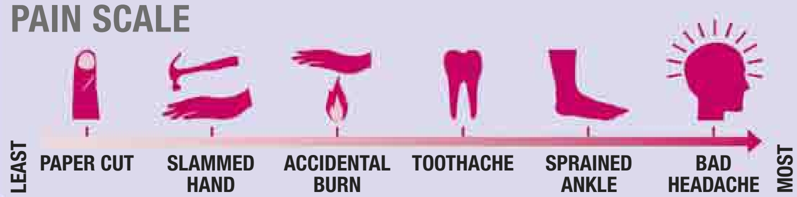
PUPIL WIDE OPEN

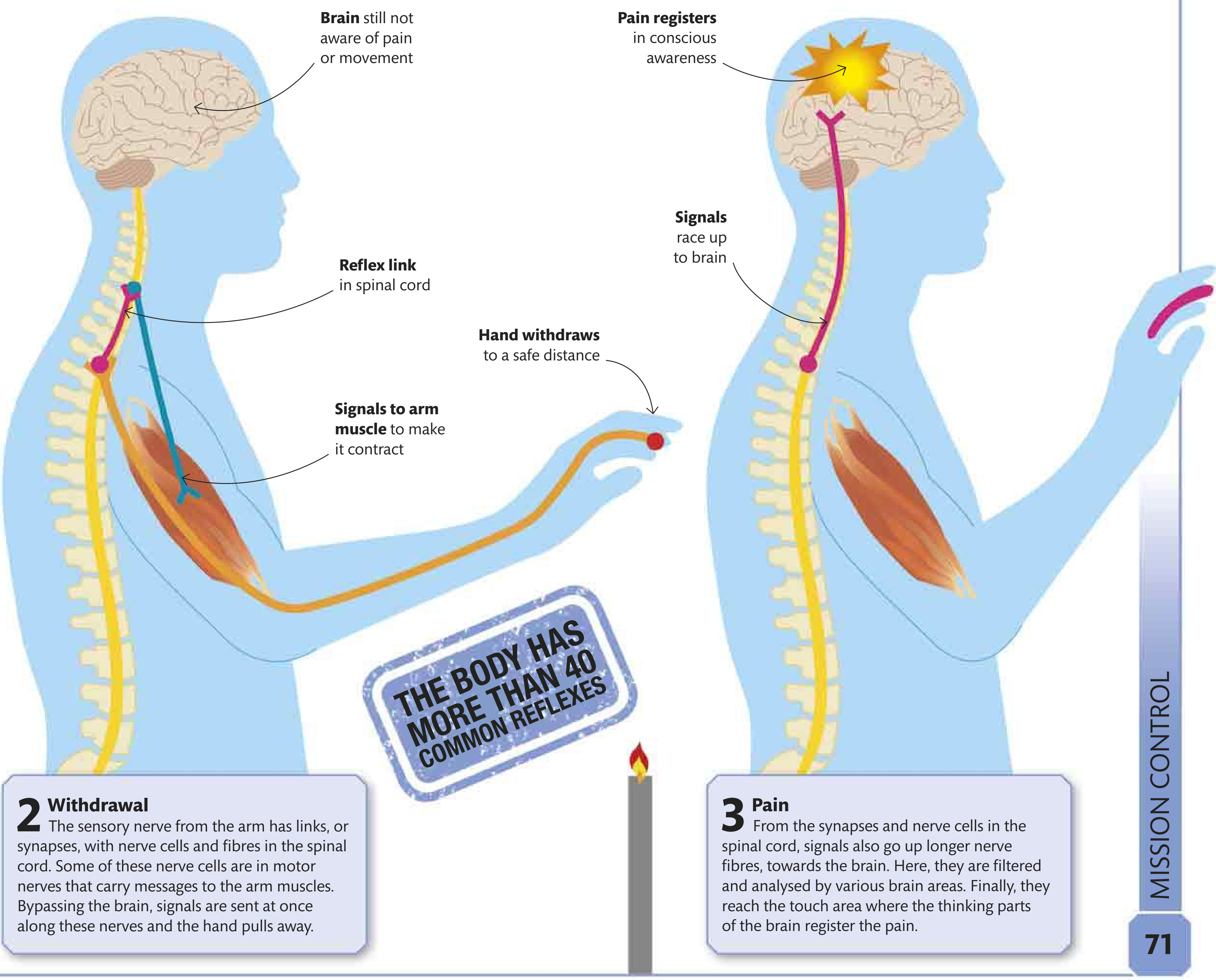
STATS AND FACTS

MOST PAINFUL BITES AND STINGS



PAIN SCALE





2 Withdrawal The sensory nerve from the arm has links, or synapses, with nerve cells and fibres in the spinal cord. Some of these nerve cells are in motor nerves that carry messages to the arm muscles. Bypassing the brain, signals are sent at once along these nerves and the hand pulls away.

3 Pain From the synapses and nerve cells in the spinal cord, signals also go up longer nerve fibres, towards the brain. Here, they are filtered and analysed by various brain areas. Finally, they reach the touch area where the thinking parts of the brain register the pain.

TOTAL RECALL

How memories are made

The brain is a giant storehouse of countless memories. But memories are not single items, each in a small place, and never changing. In fact, a memory is many patterns or pathways of nerve cell connections, spread around several parts of the brain, with links to other memories, events, and ideas. In this way, a thought, sensation, or movement can trigger one memory, which recalls another, and so on, like a chain reaction. Memories fade with time but recalling them often makes them stronger and last longer.

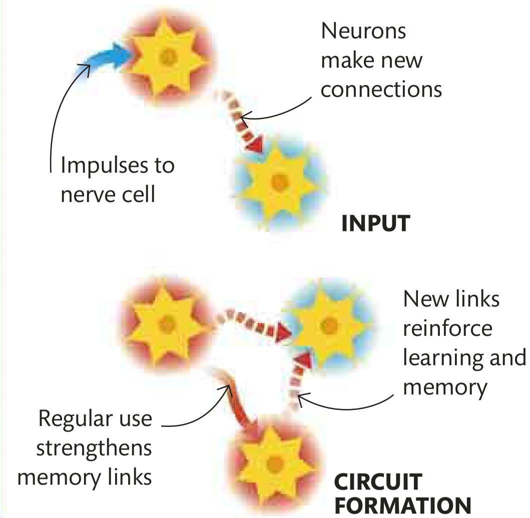
"As a digital store, the brain could hold the equivalent of 3 million hours of TV shows"

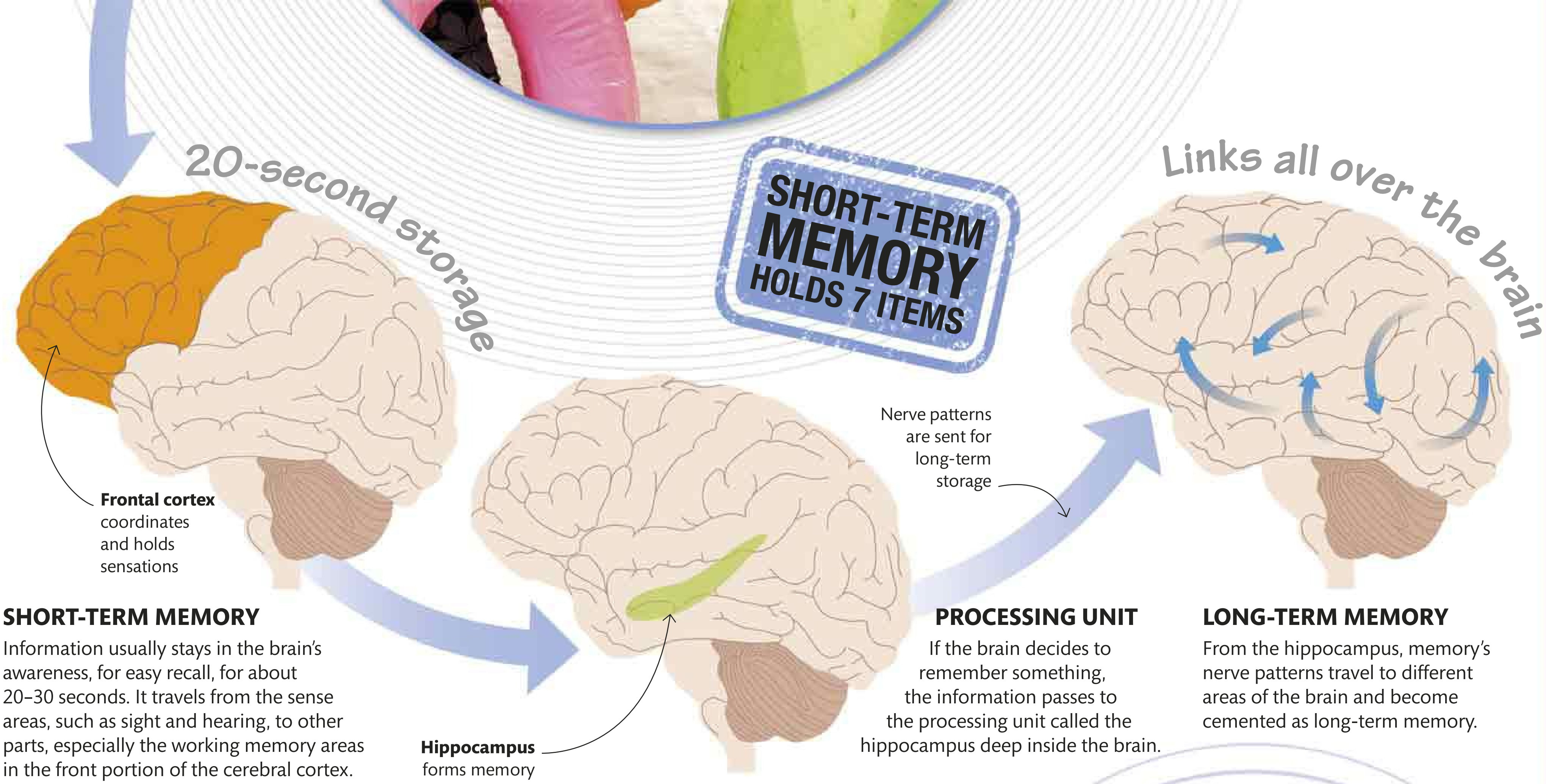
MEMORY INPUTS

The brain usually remembers groups of information. Along with the value of a written number, it may store its shape, the ink, and even the paper colour. For events such as holidays, memories retain a whole range of sights, sounds and other sensations. All five senses can feed a memory.

HOW MEMORIES ARE FORMED

A memory is a new set of connections, or synapses, between neurons. Over time, as nerve signals pass between the neurons, they set up fresh connections. The more these pathways are used, the more established the memories become. If not recalled from time to time, they are forgotten as the connections weaken.





SHORT-TERM MEMORY
Information usually stays in the brain's awareness, for easy recall, for about 20–30 seconds. It travels from the sense areas, such as sight and hearing, to other parts, especially the working memory areas in the front portion of the cerebral cortex.

PROCESSING UNIT
If the brain decides to remember something, the information passes to the processing unit called the hippocampus deep inside the brain.

LONG-TERM MEMORY
From the hippocampus, memory's nerve patterns travel to different areas of the brain and become cemented as long-term memory.

NEW TRICKS
Learning is a result of new connections between nerve cells. It takes many forms and happens in different parts of the brain. A list of words or numbers is soon forgotten unless you recall it often, or you give the list items some meaning – such as a phrase for the colours of the rainbow, VIBGYOR. Another form of learning is for a practical skill, repeated until you can do it almost without thinking.

Practical skills
Riding a bicycle, doing up buttons, or writing your name gradually become automatic muscle movements.

Communication
You learn the meaning of words, numbers, symbols, and other information used to communicate.

> "The brain's **left** side is more involved in memories for **words**, the **right** side for **pictures**"

BRAIN DOWNTIME

While you sleep

At the end of a tiring day, the body relaxes into sleep. Its various parts – such as muscles and vessels – recover and carry out necessary repairs. But the brain, similar to an offline computer, remains busy with its own internal tasks and processes. These probably include organizing thoughts and filing memories, but exactly what happens during sleep is still a mystery.

"The longest a person has gone without sleep is 449 hours"

TIME TO GO SLOW

Almost every part of the body is affected by sleep, especially the heart, muscles, lungs, and the digestive system. The senses keep sending information about these areas to the lower parts of the brain, which monitor them, and, if necessary, wake you up.

Ears

The brain ignores familiar sounds such as a ticking clock, but becomes alert to a sudden, strange noise.

Nose

The brain's smell area registers background odours, but is aroused by possible danger such as smoke.

Lungs and heart

Breathing is shallower and each heartbeat pumps less blood, but the heart rates are much the same at rest as when awake.

Eyes

Eyelids remain closed and the eyes move relatively little, except during the REM (rapid eye movement) sleep period.

Mouth

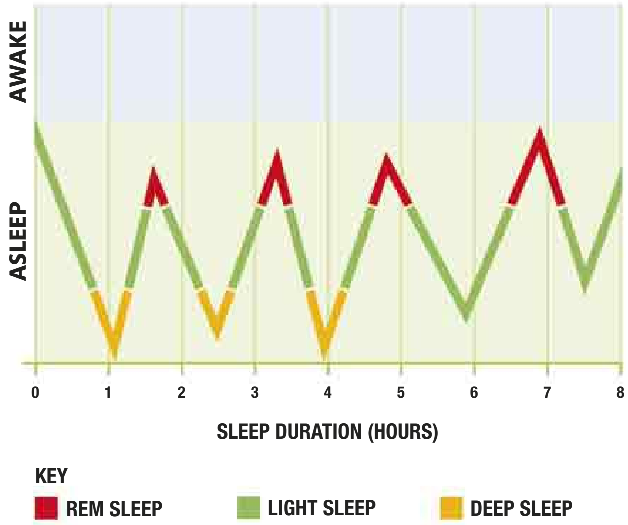
Air flow may rattle the flap at the rear roof of the mouth, the soft palate, causing an annoying noise – snoring.

Digestive system

The churning, squirming movements of the stomach and intestines lessen during sleep, but chemical digestion – done by enzymes – continues.

SLEEP PATTERNS

A typical night's sleep is not the same all through. The brain goes through several cycles of activity, including light, deep, and REM sleep. In light sleep, body processes are slow but waking is still easy. In deep sleep, systems slow down greatly and arousing the brain is more difficult. In REM sleep, the eyes flicker to and fro, breathing may speed up, and muscles can twitch. If woken at this time, the sleeper may remember dreaming.



WE SPEND ONE-THIRD OF OUR LIVES SLEEPING

DREAMING

Most dreams occur during REM sleep, although we only remember them if woken during or just after. Stress and worry seem to make dreams more frequent and disturbing. Sometimes they have links with life events, yet at other times they seem totally random.

Muscles

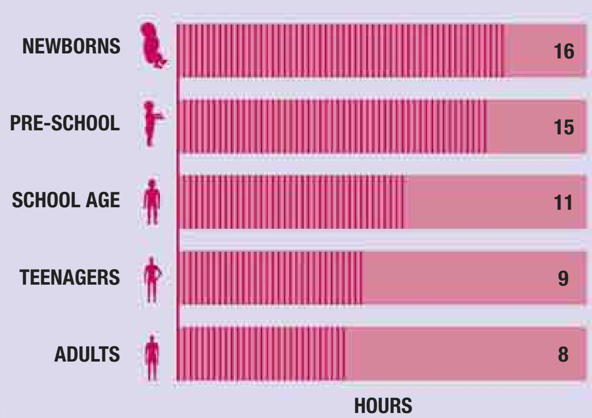
Most muscles relax, although body position shifts several times to avoid squashing blood vessels and nerves.

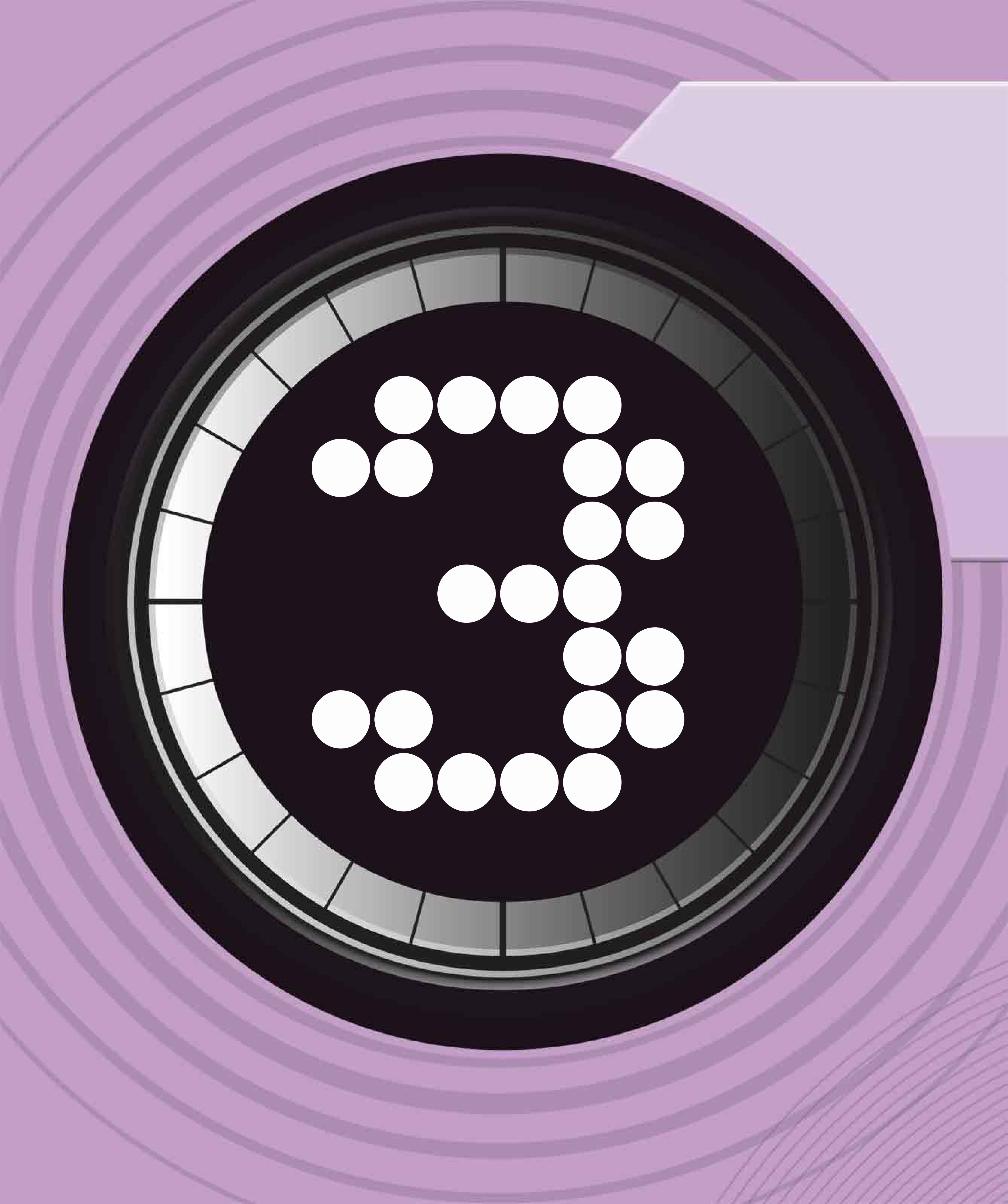
Bladder

The kidneys produce less urine during sleep, so the bladder fills more slowly than when we are awake and active. But it is usually ready when we wake up!

STATS AND FACTS

TIME SPENT SLEEPING




3

TOTALLY SENSATIONAL

Lightning flash, thunder roar, smell of fear, taste of success, even dreaded pain – the super senses track all events on, in, or around the body, and stream a never-ending torrent of information into the brain.

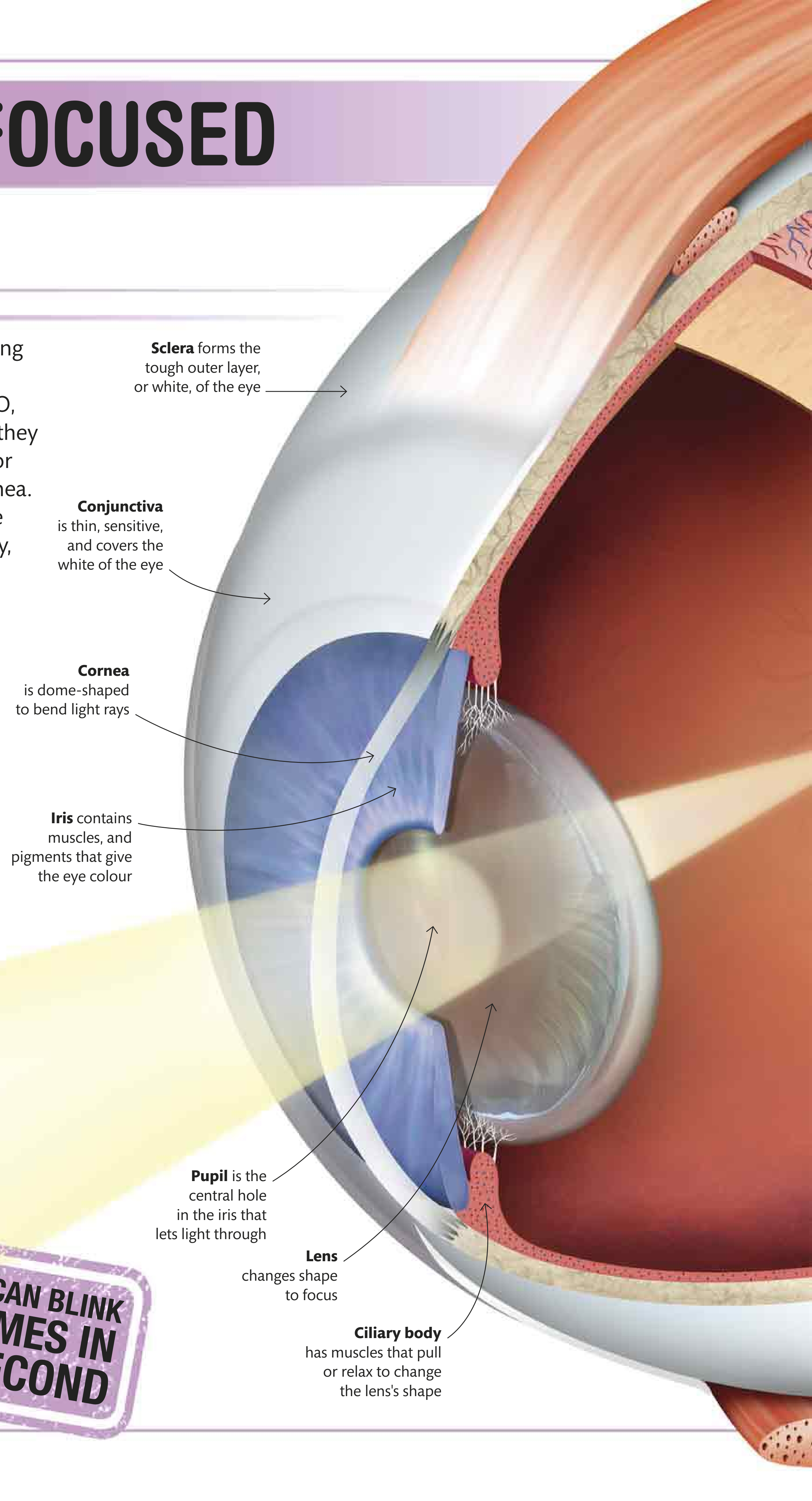
STAYING FOCUSED

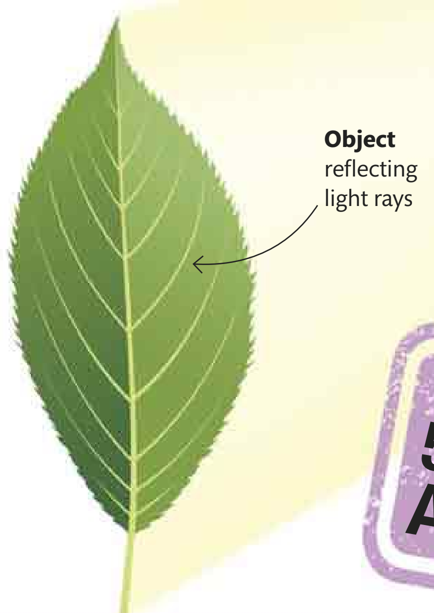
The eyeball

Your amazing full-colour, ever-moving view of the world comes into each eye through a hole hardly larger than this O, the pupil. Before light rays enter here, they pass through the sensitive front layer, or conjunctiva, and the rigid, domed cornea. After the pupil, the rays go through the lens and the vitreous humour – a glassy, jelly-like fluid – filling the bulk of the eyeball. All these structures are clear or transparent. The rays finally shine onto the light-sensitive retina.

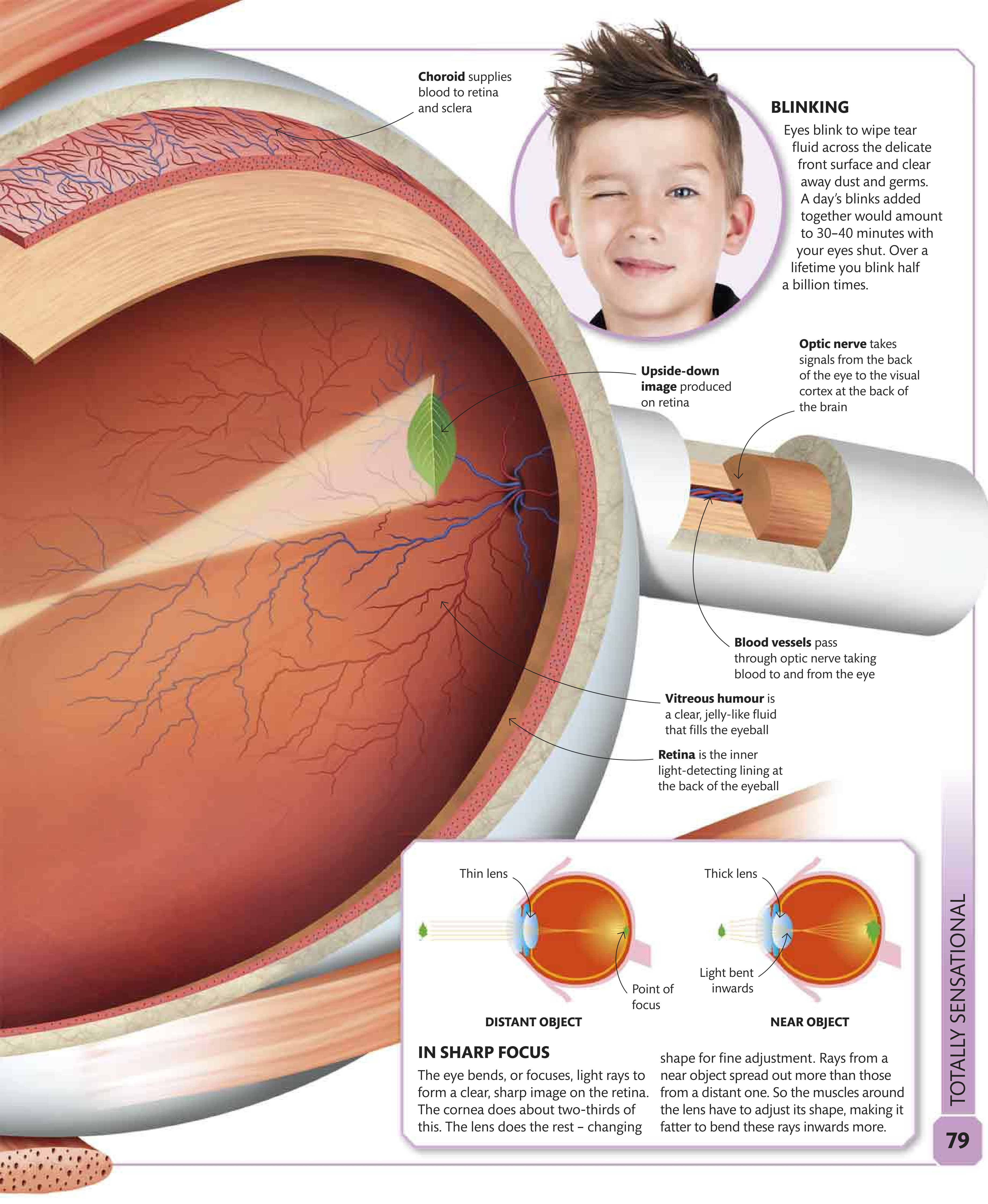
PARTS OF THE EYE

The eyeball has three layers – the white sclera, the delicate blood-rich choroid, and the retina lining the rear two-thirds. At the front the tough sclera becomes the clear curve of the cornea. The filling of jelly-like vitreous humour keeps the eye ball-shaped.





YOU CAN BLINK 5 TIMES IN A SECOND



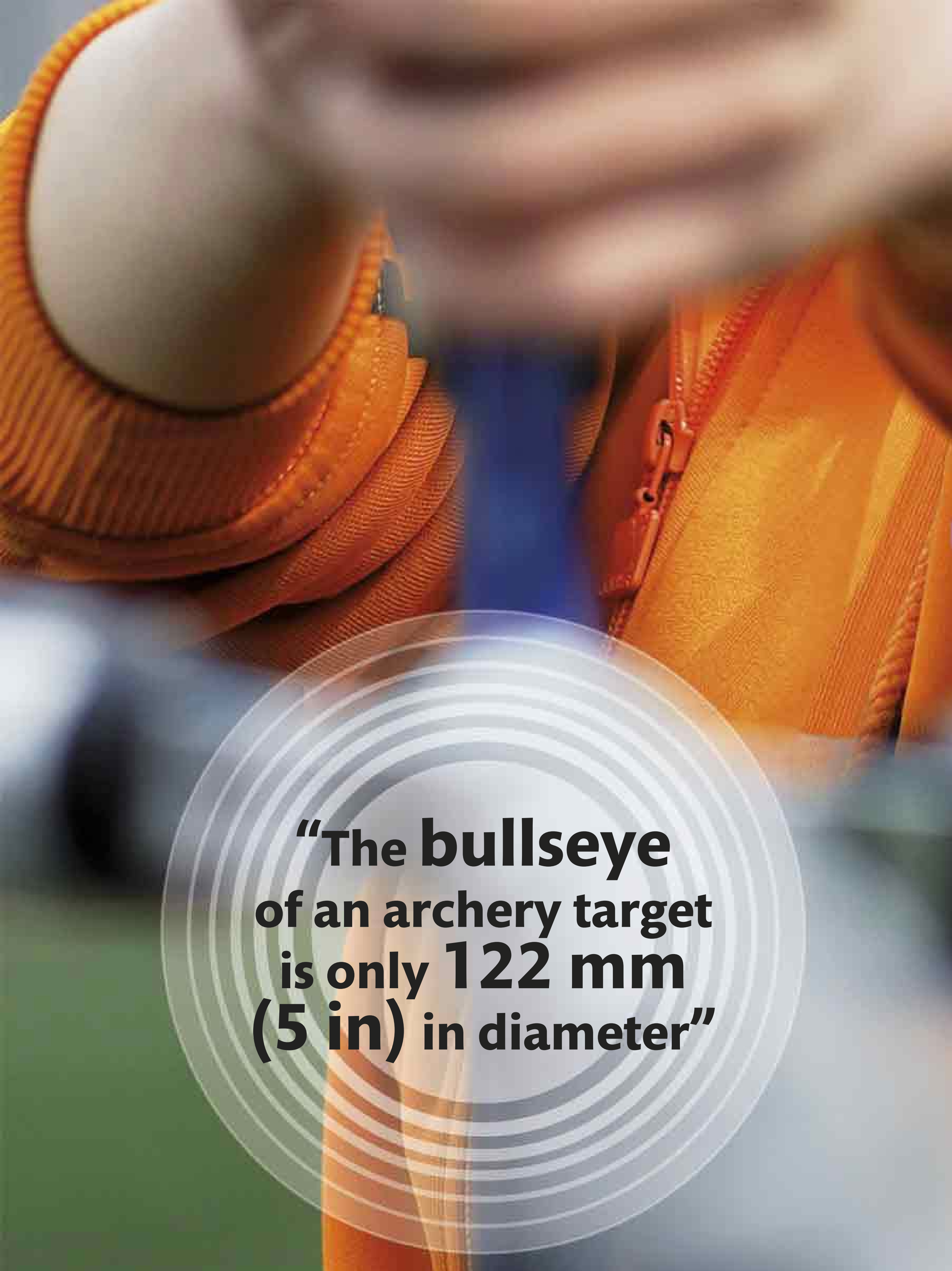
BLINKING

Eyes blink to wipe tear fluid across the delicate front surface and clear away dust and germs. A day's blinks added together would amount to 30–40 minutes with your eyes shut. Over a lifetime you blink half a billion times.

IN SHARP FOCUS

The eye bends, or focuses, light rays to form a clear, sharp image on the retina. The cornea does about two-thirds of this. The lens does the rest – changing shape for fine adjustment. Rays from a near object spread out more than those from a distant one. So the muscles around the lens have to adjust its shape, making it fatter to bend these rays inwards more.

Lining up the target
The archer squints to get a clear, one-eyed view. Her eye muscles repeatedly move the eye just a millimetre to transfer focus from the arrow, a few centimetres away, to the target, 90 m (295 ft) away.



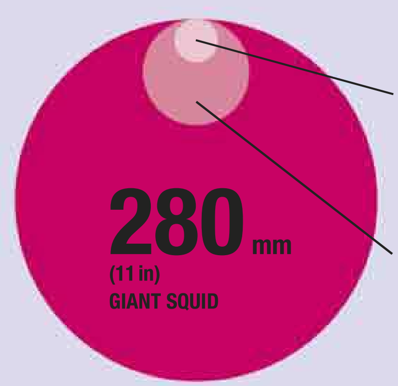
HAWKEYE

On target

The human eye is incredibly sensitive. In perfect darkness, it can detect a candle flame more than 10 km (6 miles) away! But such conditions are rare, because of light from the Moon, buildings, vehicles, and street lamps. The eye has extraordinary focusing powers, too. The muscle ring around each lens, the ciliary muscle, can alter the lens shape many times in a second. This enables you to switch focus from your hand to a distant target in less than one-tenth of a second.

STATS AND FACTS

DIAMETER OF EYEBALL



RANGE OF VISION

2.25 MILLION LIGHT YEARS
Distance to the Andromeda galaxy – the farthest the naked eye can see

EYE GROWTH AFTER BIRTH

20 PER CENT

> "The **bullseye** of an archery target is only **122 mm (5 in)** in diameter"

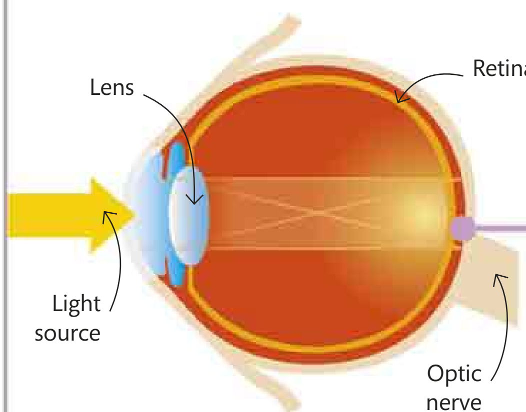
SEEING THE LIGHT

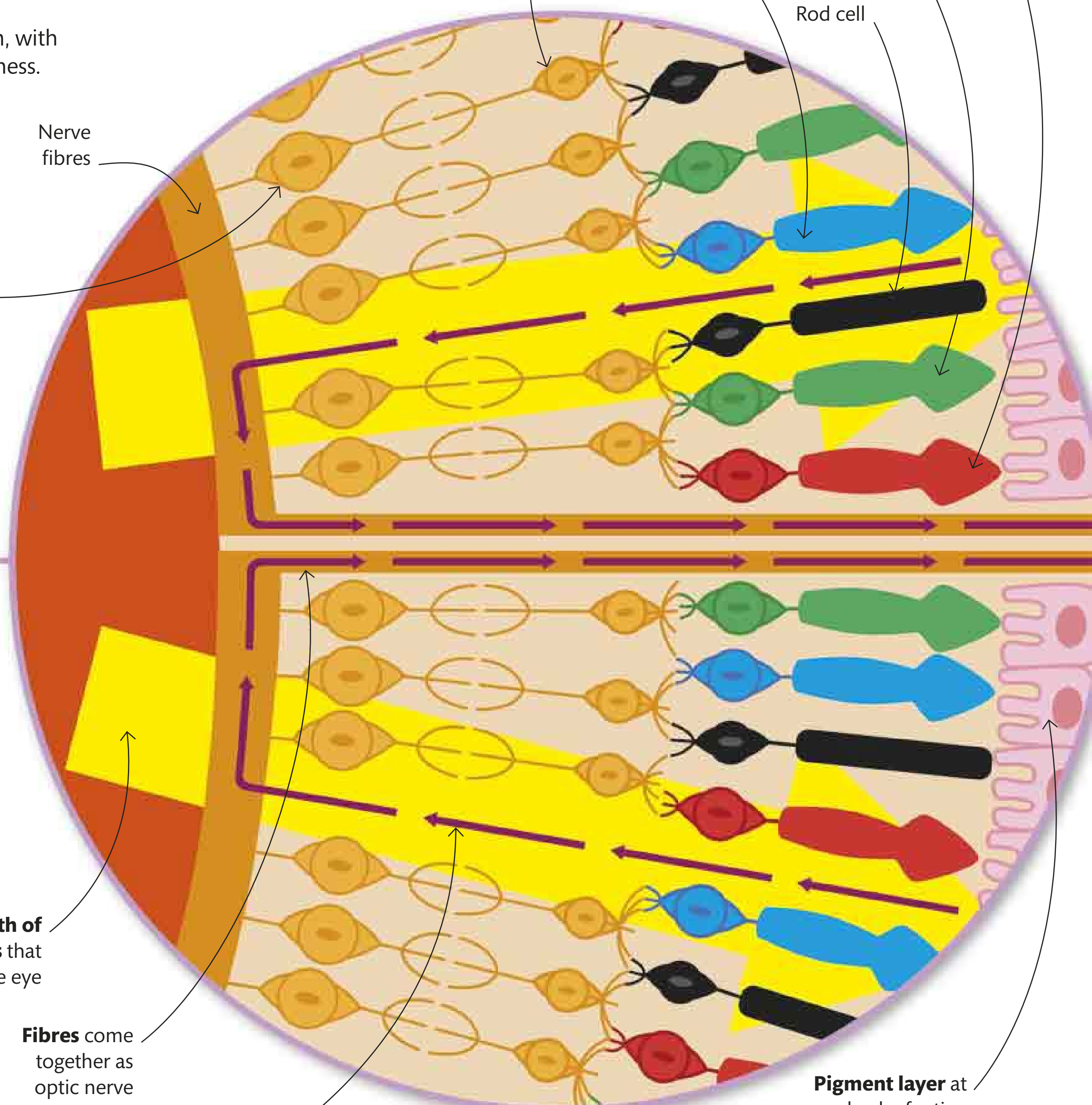
Fine detail and colour

The human eye is one of the best of all mammal eyes at seeing colours and fine details. Light rays are detected by the eyeball's inner lining, the retina, which is thinner than the paper of this page and the size of two thumbnails. Here, millions of light-sensitive cells, when struck by rays of different brightness and colour, send billions of nerve signals to the brain.

CAPTURING AN IMAGE

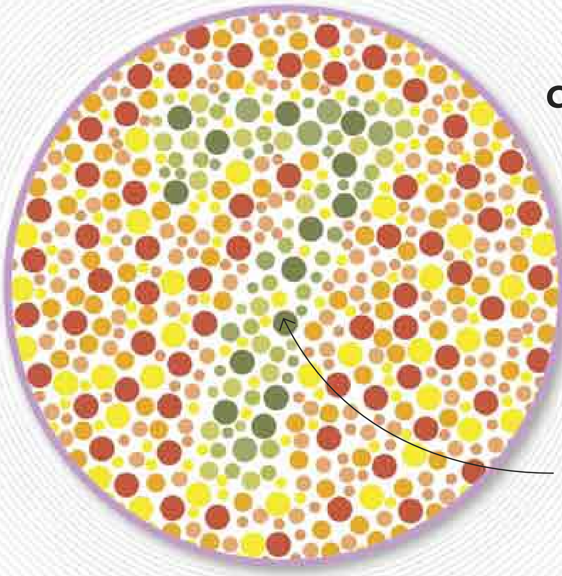
Light rays arrive at the eye in a continuous stream, with an endless variety of different colours and brightness. After being focused by the cornea and lens, the light rays pass through the clear jelly in the eyeball to the retina. The retina's task is to detect variations in colour, shape, and brightness at incredible speed – dozens of times each second.





1 Light rays from image enter the eye Light rays hit the pigment layer at the back of the retina and then pass through the light-sensitive cells, called rods and cones. These convert the information from the light rays into nerve signals.

WE CAN SEE UP TO 10 MILLION COLOURS WITH TRAINING



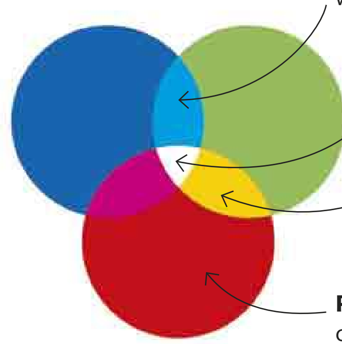
COLOUR VISION PROBLEMS

Can you see a number here? Most eyes can see 2–5 million different colours and hues. But others do not see the normal range of colours, due to an inherited condition, faulty development, injury, or disease. For example, there may be only two kinds of working cone cells rather than three.

Colour test
Those with red–green colour blindness will not be able to distinguish the number in green from the red dots around it.

MIXING COLOUR

There are three types of cone cell in our eyes that are sensitive either to red light, green light, or blue light. Colours mix to produce a variety of different colours; for example, green and red produce yellow. So yellow light affects both red-sensitive and green-sensitive cones, but not as much as pure red for red cones or green for green ones.



Secondary colours are where primary colours mix

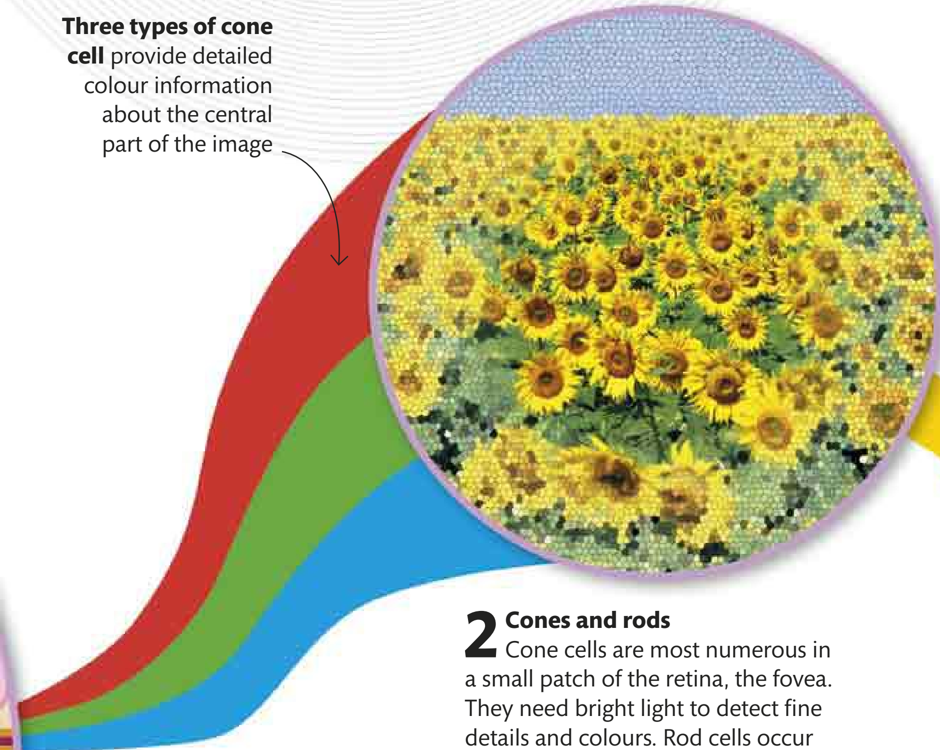
White, a mix of all three primary colours

Yellow, a secondary colour, is a mix of red and green

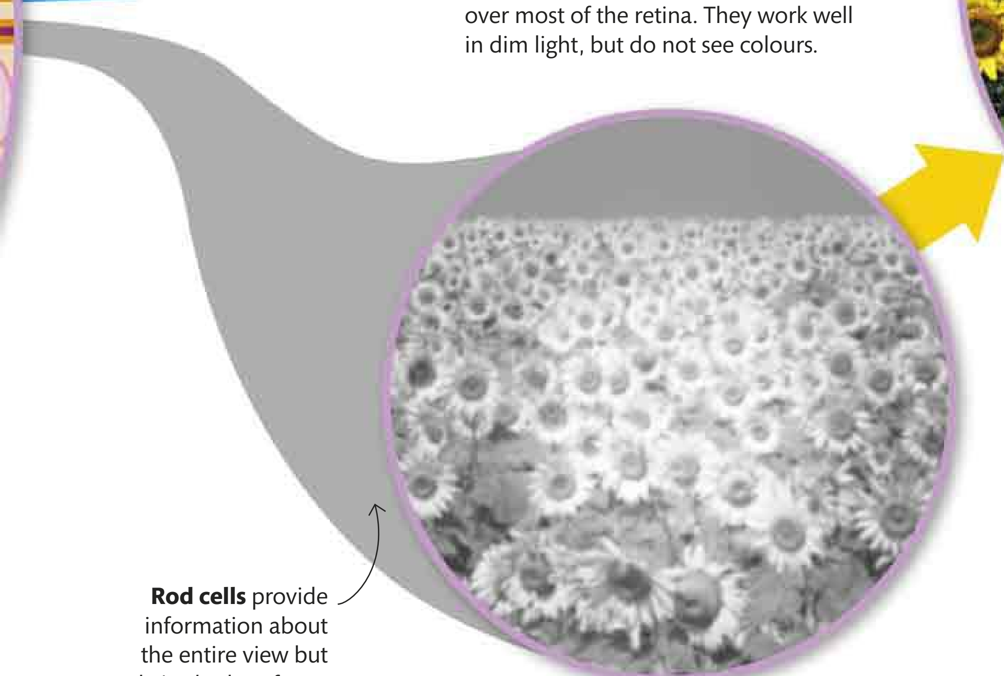
Primary colours of light are red, green, and blue

COLOUR WHEEL

Three types of cone cell provide detailed colour information about the central part of the image



2 Cones and rods
Cone cells are most numerous in a small patch of the retina, the fovea. They need bright light to detect fine details and colours. Rod cells occur over most of the retina. They work well in dim light, but do not see colours.



Rod cells provide information about the entire view but only in shades of grey

Final image in colour with greatest detail at centre

3 In the mind's eye
The detailed colour information given by the closely packed cones and the broader information, in shades of grey, from the rods is gathered by bipolar cells. Ganglion cells then combine the signals from the bipolar cells and transmit them though the optic nerve to the brain, to give a full-colour, all-over image.

READY TO FIRE

Rods and cones

Zooming into the retina of the eye reveals millions of rod and cone cells, standing like people in a gigantic crowd. Each is ready to fire nerve signals when enough light of the right colour and intensity shines on it. Human eyes have cones for red, green, and blue light. Cones are tiny – about 100 cones on top of each other would be as high as this letter I – while rods are slightly slimmer and taller. In the whole retina there are 20 times more rods than cones.

STATS AND FACTS

TYPES OF CONE CELLS

Red Green Blue
HUMAN'S EYE

Yellow Blue
DOG'S EYE

Red Green Blue Ultraviolet
BIRD'S EYE

NUMBER OF CONE CELLS

HUMAN: 6–7 MILLION

DOG: 1 MILLION

ROD CELLS IN HUMAN EYE: 120 MILLION

Sight 'n' seeing

Shown here are rods (in green) and cones (in blue), 5,000 times their actual size. Rods and cones are packed into the retina at the back of the eye, from where they send signals to the brain.

"It takes 100 times more light energy to make a cone cell generate nerve signals than a rod"

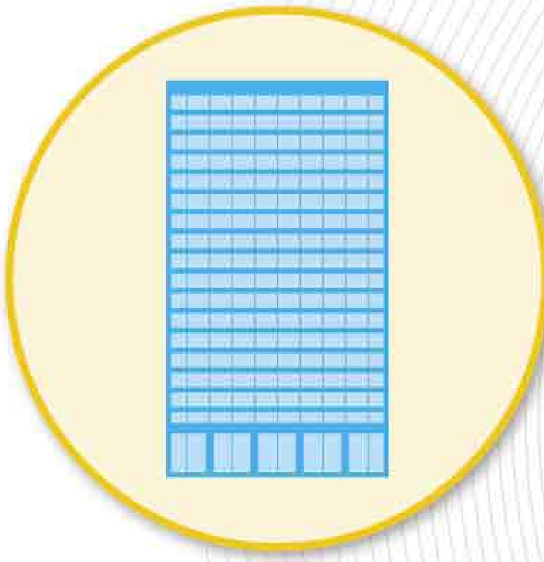
KEEP IT IN PERSPECTIVE

3D vision

Unlike a horse or a whale, which have eyes on the side of their head, a human's eyes both face forwards and see almost the same scene, but from slightly different angles. Just open and close each eye in turn to test this out. Comparing these two views in the brain, and using clues such as size, colour, and blur, gives us a tremendous ability to judge depth and distance, and see in glorious three dimensions (3D) – height, width, and depth.

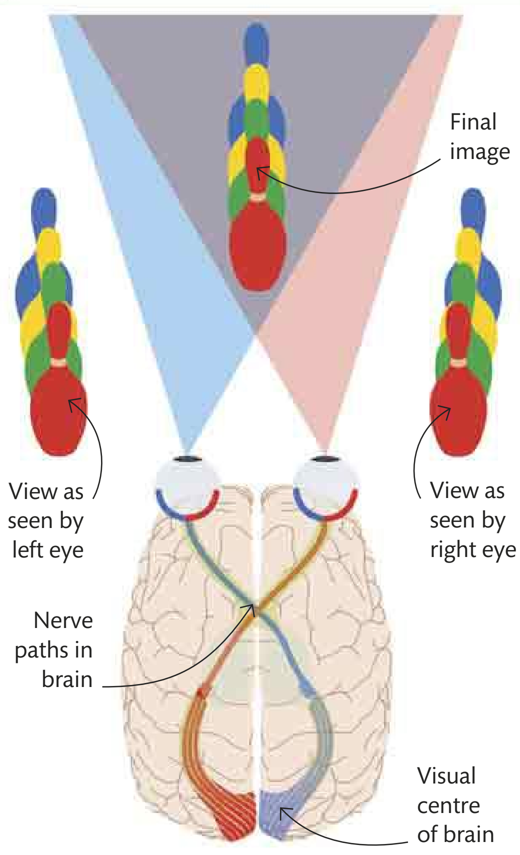
WORKING OUT A SCENE

This city street scene has all the components to help our eyes and brain create a complete image. Things like subtle changes in colour, differences in size, and receding lines all contribute to the visual clues.



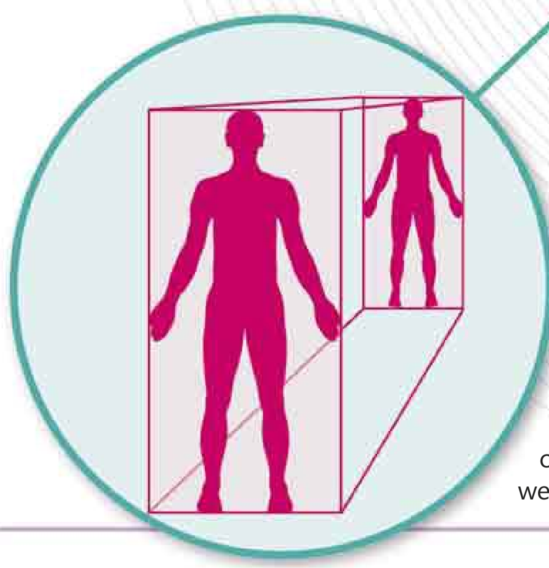
ACTUAL SIZE

We know the real sizes of objects such as people, cars, lorries, and various animals. Checking their size in a scene such as a busy street allows us to guess how far away they are.



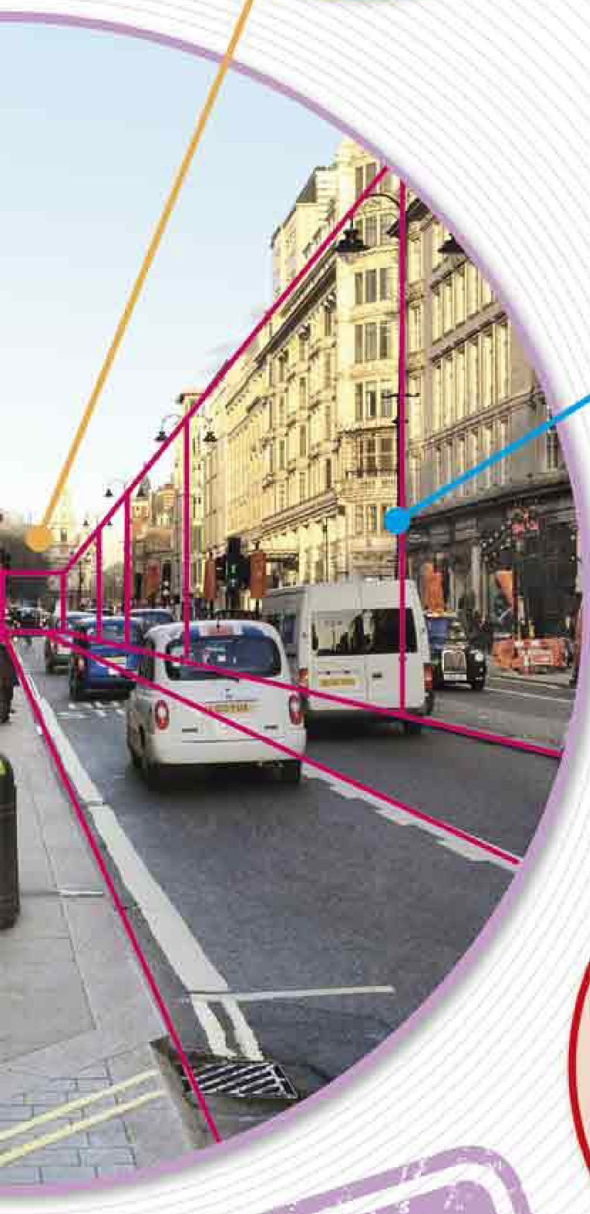
BINOCULAR VISION

Each eye sees a scene from its own angle. The vision centre of the brain compares the left half of the left eye's view with the left half from the right eye, and similarly for the right halves. The more the two views of an object differ, the nearer it is. This is known as binocular or two-eye vision.



RELATIVE SIZE

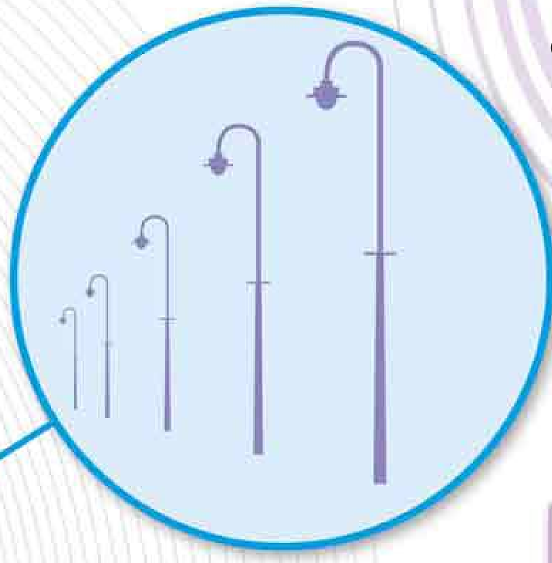
Comparing the sizes of similar objects helps us estimate their distance from us. If there are two similar vehicles or people in view, for example, and one is twice as big as the other, we assume it is much nearer.



COLOUR, FADE, AND SHADOW

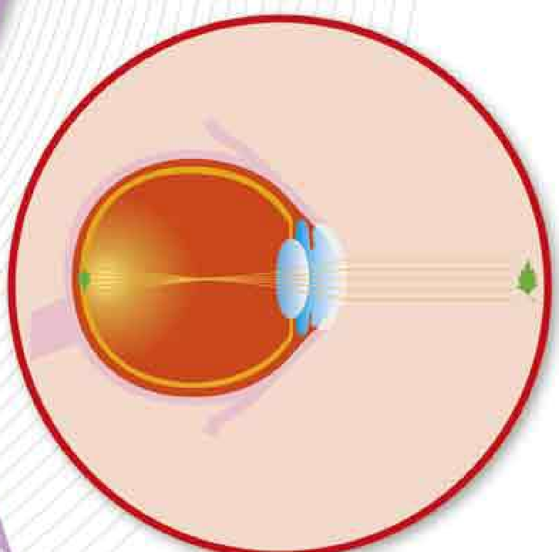
The same colour will look different the further away it is. It will get paler and more faded. Also, the faraway view is hazier and more blurred – sometimes due to dust particles in the air. Our brain learns this, which helps us judge distance.

"Good eyesight can detect movements of less than 1 m (3 ft) at a distance of 100 m (328 ft)"



PARALLEL AND PARALLAX

Lines that are the same distance apart seem to come closer together as they go off into the distance. Also, shifting the head from side to side makes near objects move more than far ones. This is called parallax.



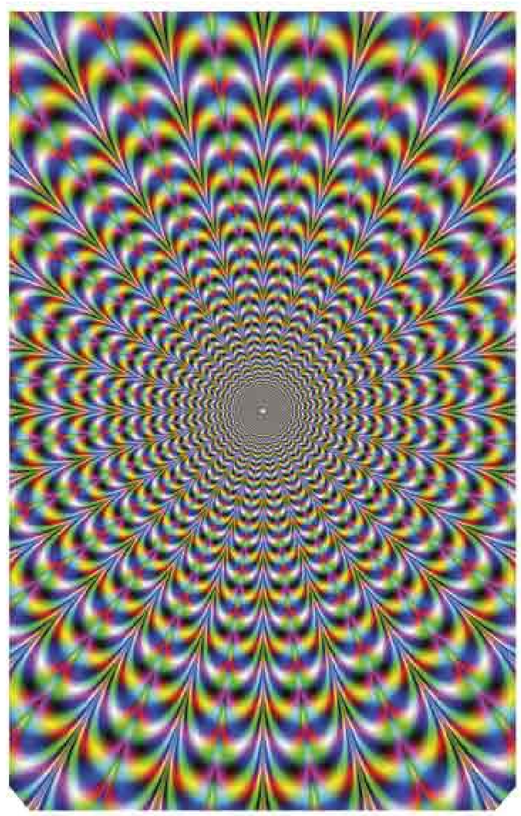
EYE FOCUS AND ANGLE

The brain detects the eye's lens becoming thicker to focus on near objects, and thinner for distant ones (see pp. 78–79). Both eyes swivel inwards to look at nearer things.

CROWDED AREAS MAKE OBJECTS LOOK NEARER

PLAYING WITH PERSPECTIVE

A two-dimensional (2D) image can look 3D using features such as perspective and shadows. Playing with these can produce an optical illusion. This does not trick the eyes, which record the scene. Instead, it fools the brain as it tries to turn 2D into 3D.



COMPLETE CONTROL

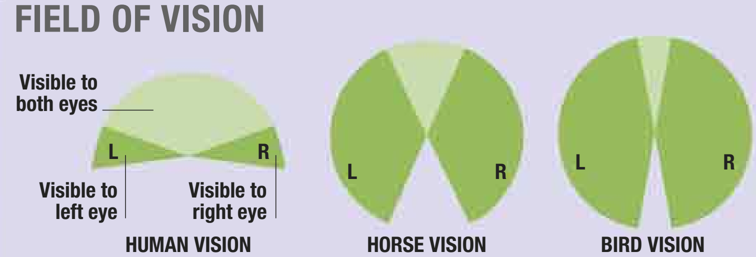
Total focus

"The human eye can see a bright flash of only 4 ms (1⁄250 of a second)"

Our two forward-facing eyes, each looking at a slightly different angle, let us judge distances more accurately than almost any other animal. As an object approaches it triggers more cells in the retina. Muscles adjust the lens to maintain a sharp focus. Both eyes move to look directly at the object, their muscles reacting to length changes of just 0.2 mm. Processing all this information, in some cases up to 100 times per second, allows humans to track motion in incredible detail.

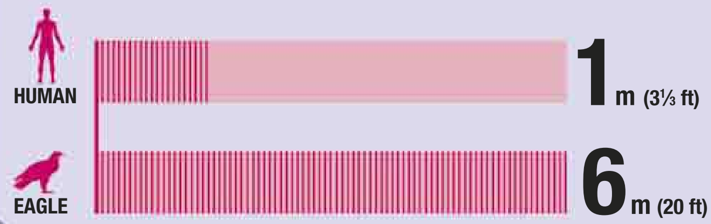
STATS AND FACTS

FIELD OF VISION



SHARPNESS OF VISION

An eagle's eyesight is five times sharper than a human's



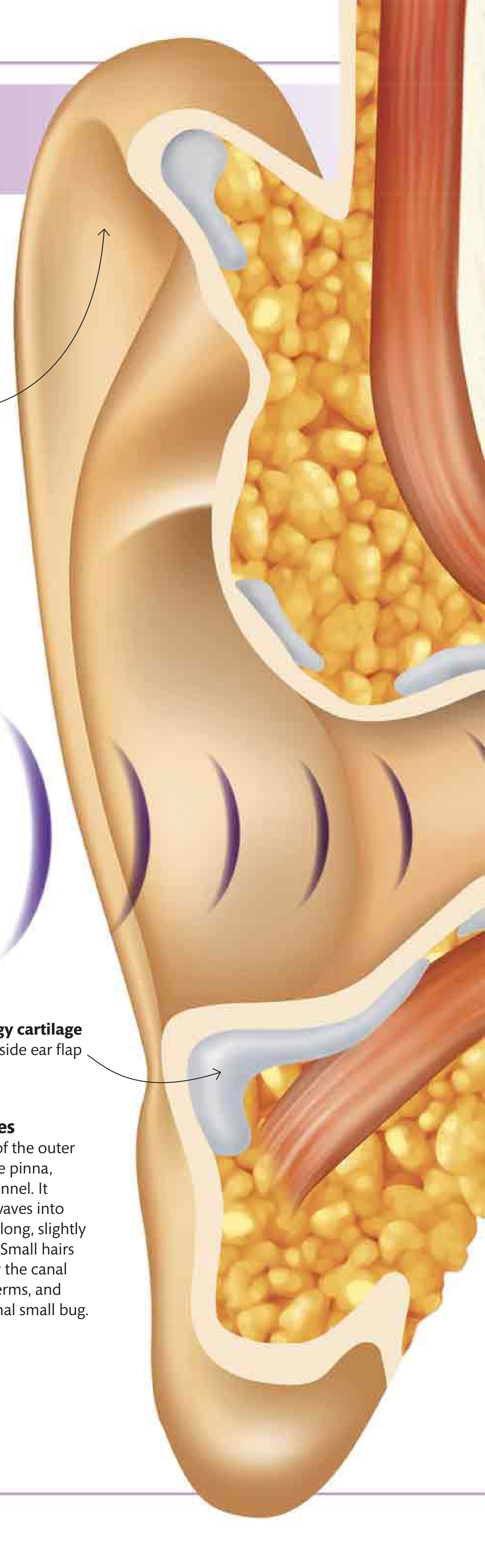
Set to serve

Once it reaches the top of its travel, the tennis ball starts to fall faster and faster. At the precise moment, the server must catch it in the racquet's "sweet spot" to smash it away at over 240 km/h (150 mph).

WIRED FOR SOUND

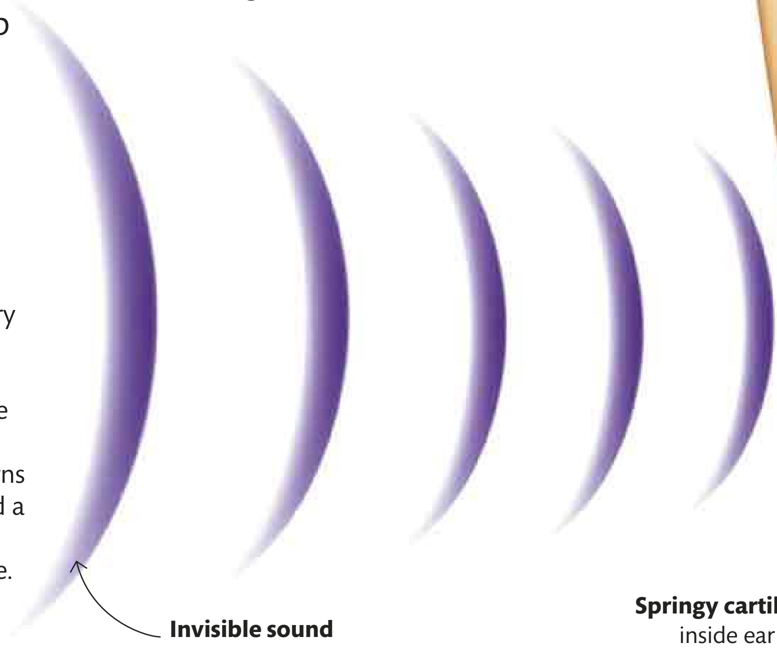
How ears work

Ears are much more than flaps on either side of the head. They hear an immense range of sounds, varying in volume from the faintest whisper to a jet's mighty roar, and in pitch from deep rumbling thunder to a high, shrill bird song. The ear even has its own in-built protection system. On hearing a very loud sound, within one-tenth of a second, two tiny muscles pull on miniature bones deep in the middle ear. This reduces their vibration movements and so protects the incredibly delicate inner ear from damage. The ears also contain parts that help maintain balance.



INTO THE EAR

Invisible sound waves in the air travel along the ear canal to the middle ear, where the eardrum changes them into patterns of very fast to-and-fro movements, or vibrations. These vibrations pass across the middle ear and into the inner ear where the snail-shaped cochlea changes them into patterns of nerve signals. The signals speed a short distance along the cochlear nerve to the brain's hearing centre.

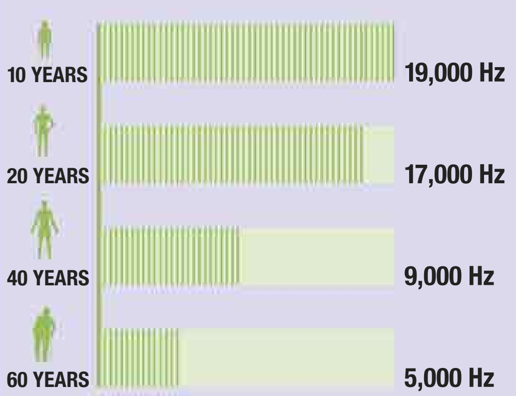


1 Collecting sound waves

The central area of the outer ear flap, called the pinna, is shaped like a funnel. It channels sound waves into the 2.5 cm- (1 in)-long, slightly curved ear canal. Small hairs and wax made by the canal lining trap dirt, germs, and even the occasional small bug.

STATS AND FACTS

HEARING RANGE CHANGE



If unrolled, the cochlea, which is about the size of a pea, would be

31.5 mm (1¼ in)

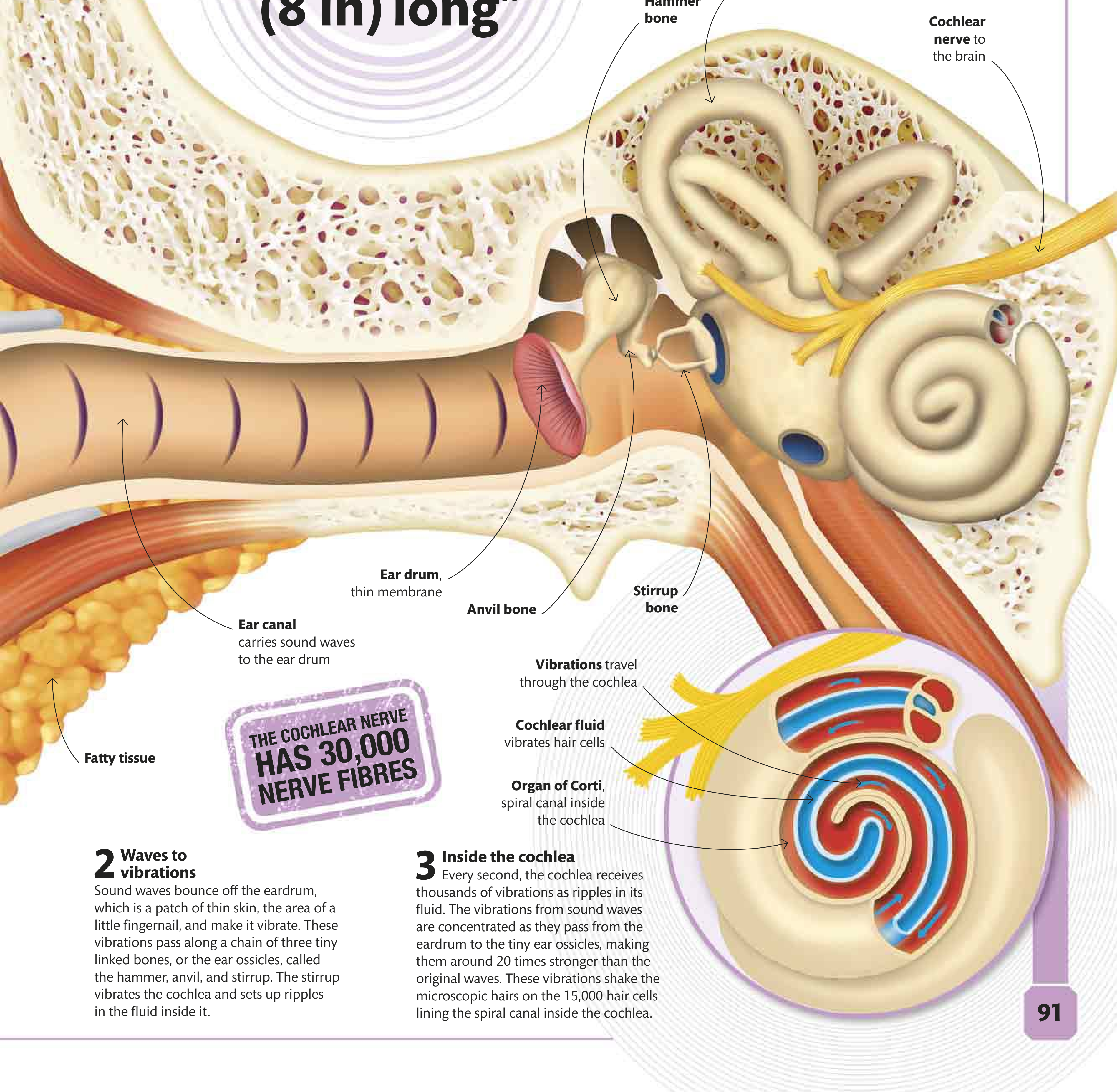
Inside each cochlea, there are around

15,000

hairs, all of which could fit on the head of a pin

“Ear hairs can grow to more than 20 cm (8 in) long”

4 To the brain
Different hair cells respond to different sounds – low, high, quiet, and loud. When their micro-hairs vibrate, the cells pass on the pattern of the vibrations as nerve messages. These flash along the fibres that form the cochlear nerve, which carries them to the brain.



THE COCHLEAR NERVE HAS 30,000 NERVE FIBRES

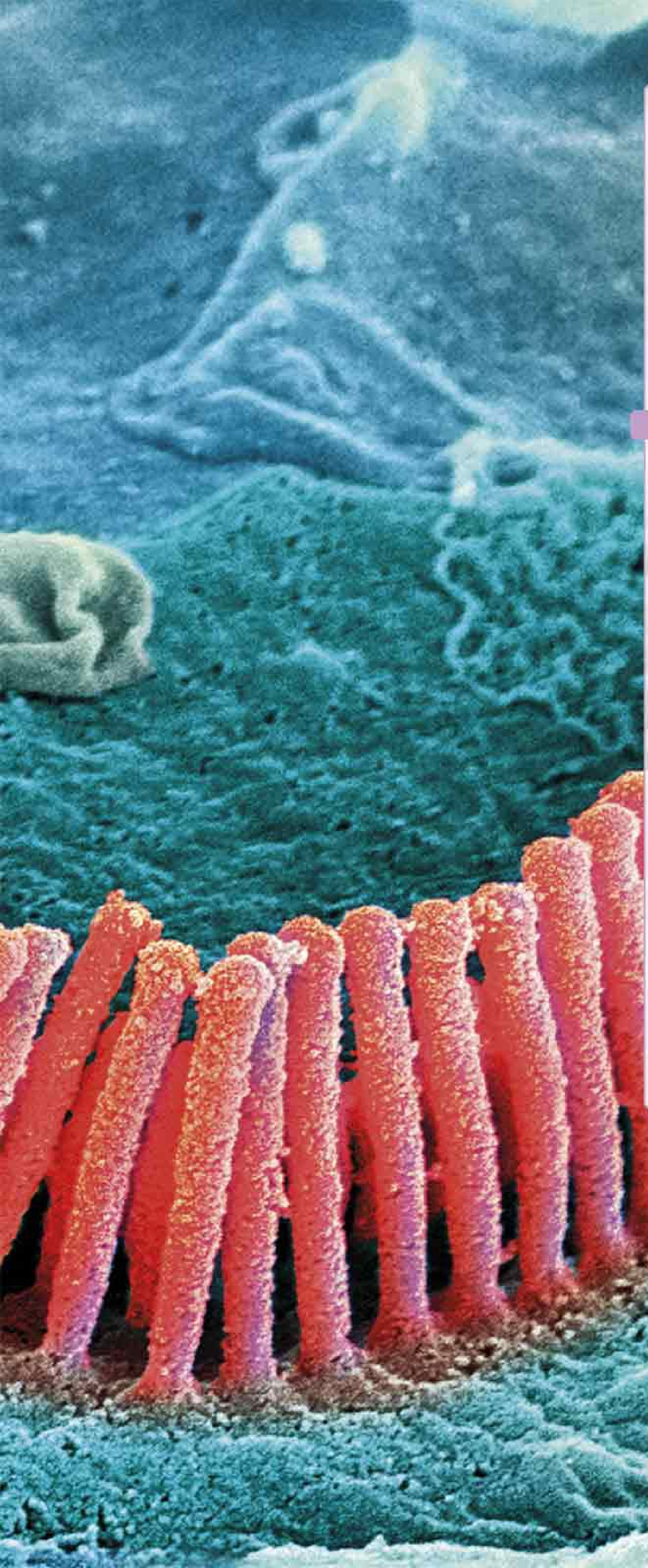
2 Waves to vibrations
Sound waves bounce off the eardrum, which is a patch of thin skin, the area of a little fingernail, and make it vibrate. These vibrations pass along a chain of three tiny linked bones, or the ear ossicles, called the hammer, anvil, and stirrup. The stirrup vibrates the cochlea and sets up ripples in the fluid inside it.

3 Inside the cochlea
Every second, the cochlea receives thousands of vibrations as ripples in its fluid. The vibrations from sound waves are concentrated as they pass from the eardrum to the tiny ear ossicles, making them around 20 times stronger than the original waves. These vibrations shake the microscopic hairs on the 15,000 hair cells lining the spiral canal inside the cochlea.

Good vibrations

Seen at 100,000 times their size, micro-hairs poke from the dished surface of a single outer hair cell. This is surrounded by ridges, and beyond are the similar down-curved surfaces of neighbouring cells.

"An average ear produces enough wax in one year to fill an egg cup"



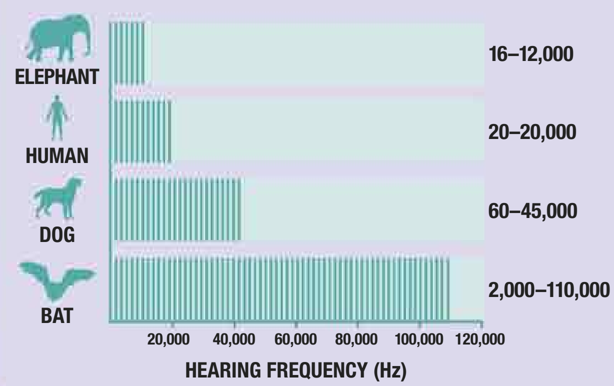
HAIRS THAT HEAR

Inside the cochlea

Deep in the ear, the cochlea — itself the size of a pea — contains around 15,000 specialized microscopic hair cells. Each has a batch of even tinier micro-hairs called stereocilia on its surface. The hairs jut into a sticky fluid called endolymph and touch a jelly-like sheet, both of which vibrate with sound. There are two sets of hair cells – inner and outer. The 3,000 inner cells do most of the hearing. Another 12,000 outer hair cells boost the vibrations to make hearing extra-sensitive.

STATS AND FACTS

HEARING RANGE



ANIMAL SOUNDS

200 dB
Pistol shrimp claw snapping

188 dB
Blue whale song

110 dB
Human shout

BALANCING ACT

Staying upright

The unstable, two-legged human body has an astonishing split-second ability to stay upright and move without falling. Yet balance is not a single sense. It combines sensory information from the inner ears, the skin, muscles, and joints. Every second they send thousands of messages to the brain, which monitors the information and sends out instructions to hundreds of muscles – usually automatically!

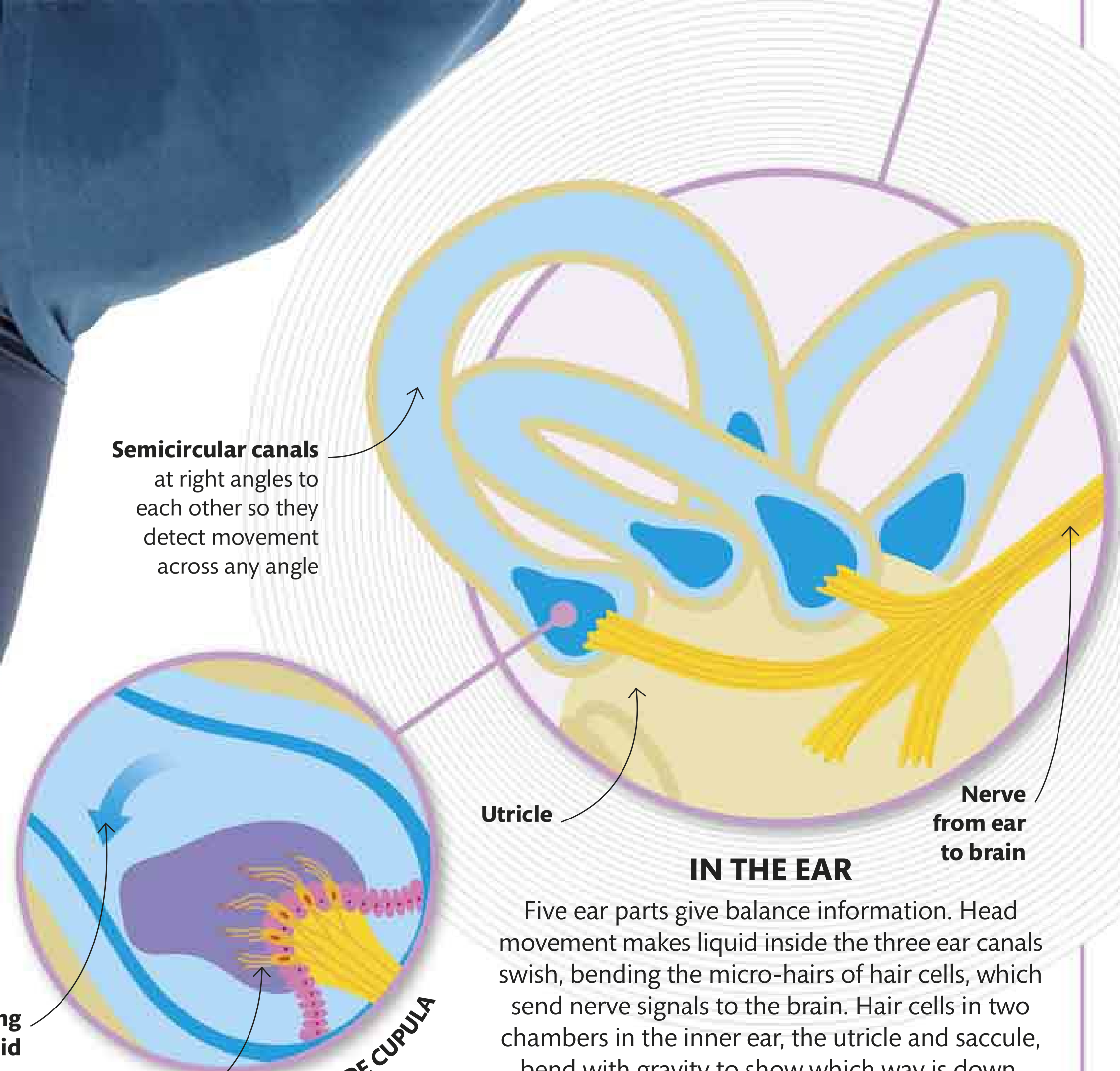
THE EAR'S BALANCE ORGANS ARE PEA-SIZED

HOW WE BALANCE

Balance is a continual process that relies on inputs from pressure sensors in the skin, stretch sensors inside body parts, fluid-filled canals and chambers deep in the ears, and even the eyes. The brain compares these inputs in the cerebellum, at the lower rear part of the brain, and structures called basal ganglia, which are deep in the brain's centre.

It takes 0.03 seconds to correct sudden imbalance

“Even standing still uses over 300 muscles”



IN THE EAR

Five ear parts give balance information. Head movement makes liquid inside the three ear canals swish, bending the micro-hairs of hair cells, which send nerve signals to the brain. Hair cells in two chambers in the inner ear, the utricle and saccule, bend with gravity to show which way is down.

DIZZINESS

Many sudden, fast-changing movements make the liquid in the inner ear slosh around, even after the motion stops and the eyes show the head is now still. The brain is confused by these conflicting messages, especially when the movements are unnatural – such as being thrown around and upside-down on a rollercoaster. It takes up to 30 seconds for the liquid's swishing to fade so that the brain can recover.

STATS AND FACTS

TIGHTROPE CROSSING

Fastest 100 m (328 ft) tightrope walk
45 seconds

Longest tightrope crossing by bicycle
71.6 m
(235 ft)

Most skips on a tightrope
1,323

Total volume of all inner ear fluid is less than **1/10** of a teaspoon

Your body uses **50%** of its muscles to balance while standing still

SUPER BALANCE

Sure-footed ride

Standing upright and well-balanced, even on a steady surface, means over 300 muscles need to make tiny alterations many times each second. On a surface that moves suddenly and unpredictably, in a split second, the challenge increases 100-fold. Balance sensors in the ears, muscles, joints, and skin fire constant streams of information into the brain – millions of signals per second! The brain continually decides on muscles to keep the body steady. Bend the back? Hold out an arm? Shift a foot?

STATS AND FACTS

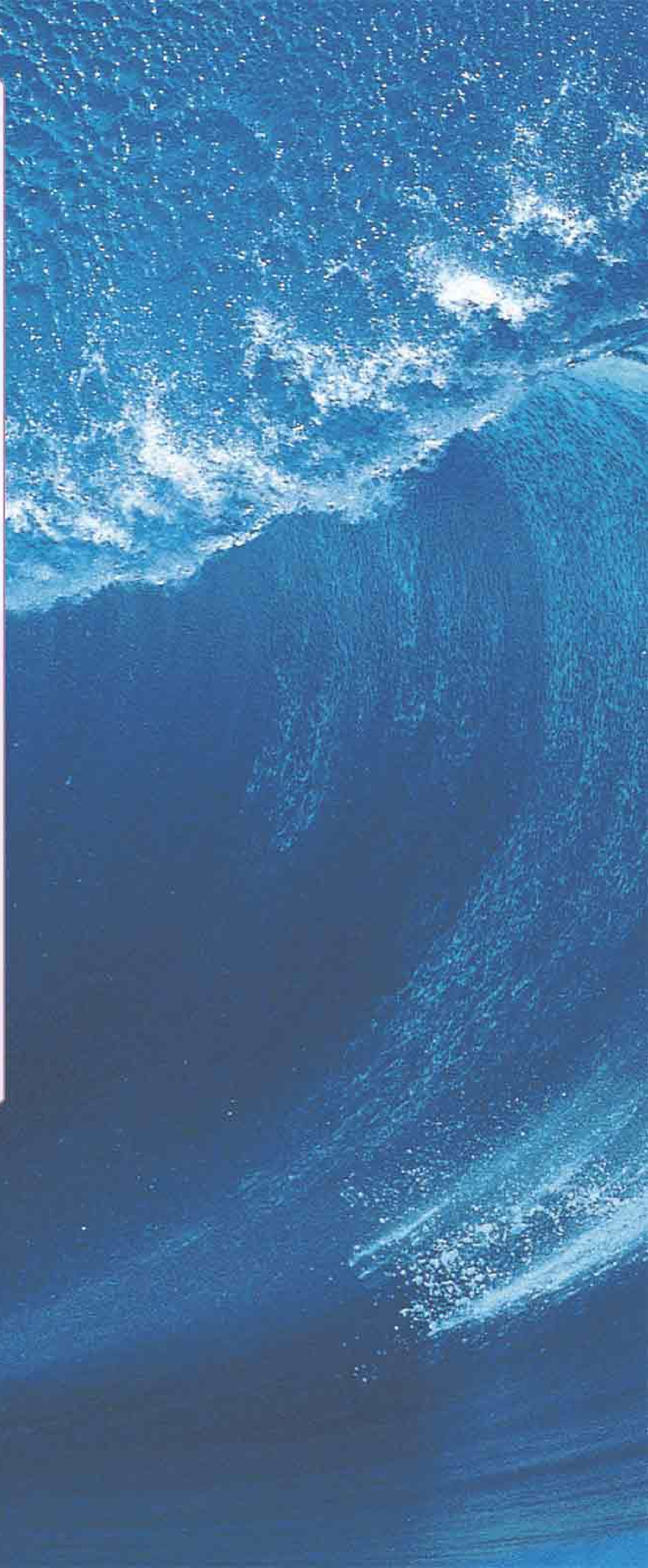
STAYING ON BOARD

Longest surfing marathon
313 waves in **29** hours

Windsurfing record on a single wave
7 minutes **3** seconds

Longest surf on a continuous wave
3 hours **55** minutes

Most people on a surfboard **47**



Riding giants
Every wave is unique, with tiny variations in water speed, depth, current, angle of slope, and wind pressure. The surfer rides these unpredictable waves with the calculated slide of a foot.

"Training can **improve** balance by more than **10 times**"

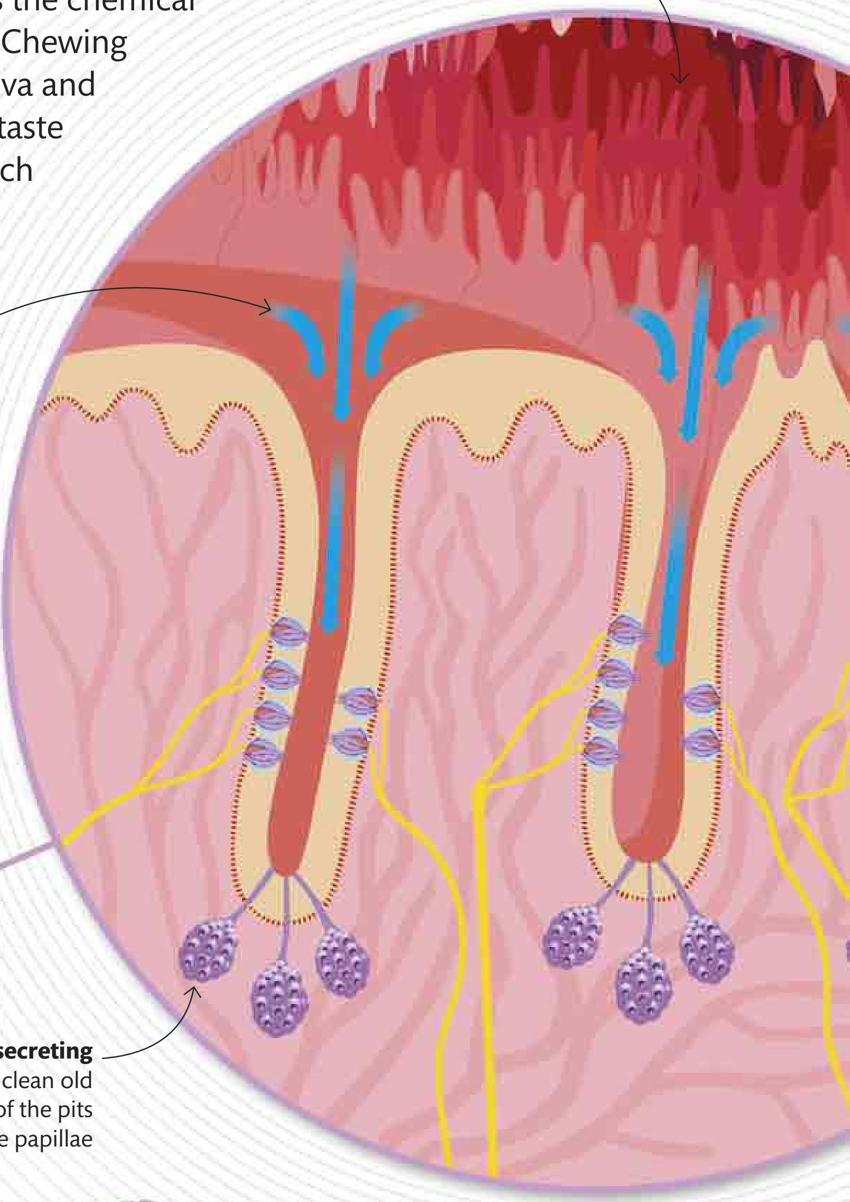
TASTY!

How we taste food

Taste acts like a sentry to the digestive system. On one hand it provides fantastic flavours that signal a delicious meal; on the other, it warns of bad or rotting foods that might poison the body. Like smell, taste is a chemosense – it detects the chemical substances that give flavours to food and drinks. Chewing releases these substances, which dissolve in saliva and seep into thousands of microstructures called taste buds. Here they touch taste receptor cells, which fire nerve signals to the brain.

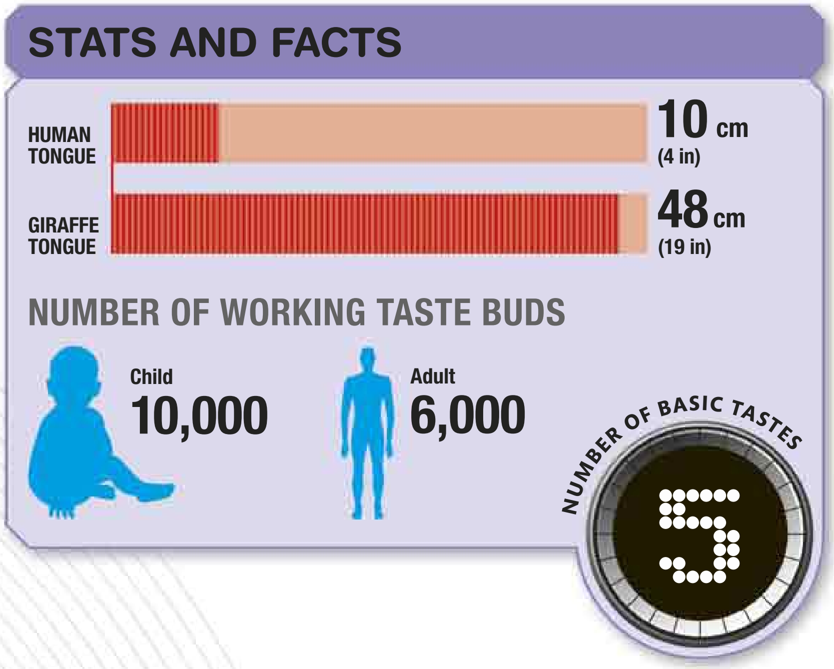
MIGHTY MUSCULAR

The tongue is almost all muscle, making it powerful and flexible. More than four-fifths of the taste buds lie on its upper surface, sides, and tip. There are also taste buds scattered on the inner lips, insides of the cheeks, roof of the mouth (palate), throat, and epiglottis.



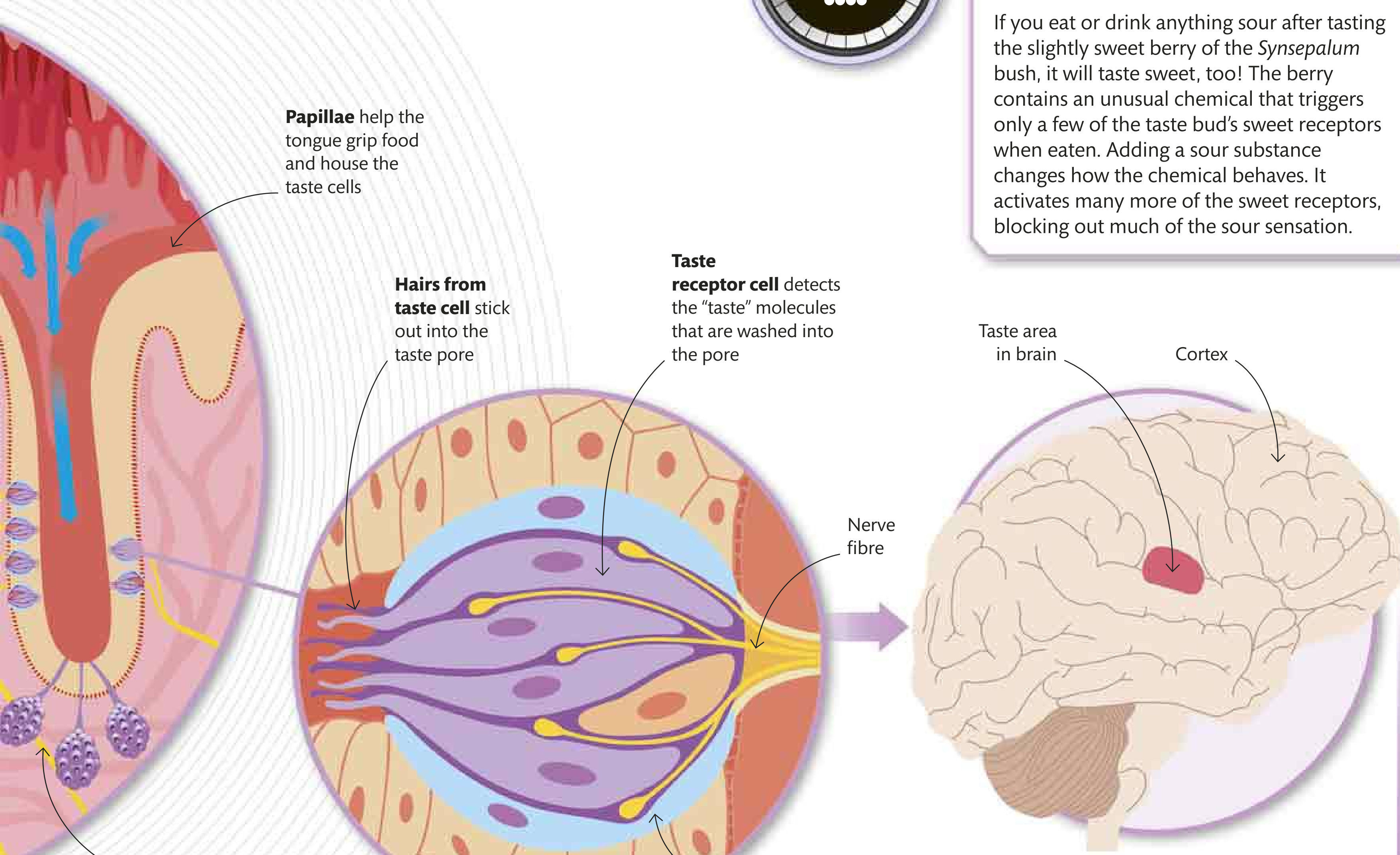
A TONGUE PRINT IS AS UNIQUE AS A FINGERPRINT

1 Papillae
The tongue's upper surface is coated with hundreds of tiny lumps and bumps called papillae. Most of the taste buds are located around the sides of papillae, or in the gaps between them. Each taste bud is just 0.05 mm across.



MIRACLE FRUIT

If you eat or drink anything sour after tasting the slightly sweet berry of the *Synsepalum* bush, it will taste sweet, too! The berry contains an unusual chemical that triggers only a few of the taste bud's sweet receptors when eaten. Adding a sour substance changes how the chemical behaves. It activates many more of the sweet receptors, blocking out much of the sour sensation.



2 Taste buds

Each bud looks like a micro-orange with about 25 taste receptor cells plus support cells. The tips of the receptor cells have narrow, hair-like structures that cluster at a hole, called the taste pore, in the tongue's surface. The other ends of the receptor cells connect to nerve fibres.

3 The brain

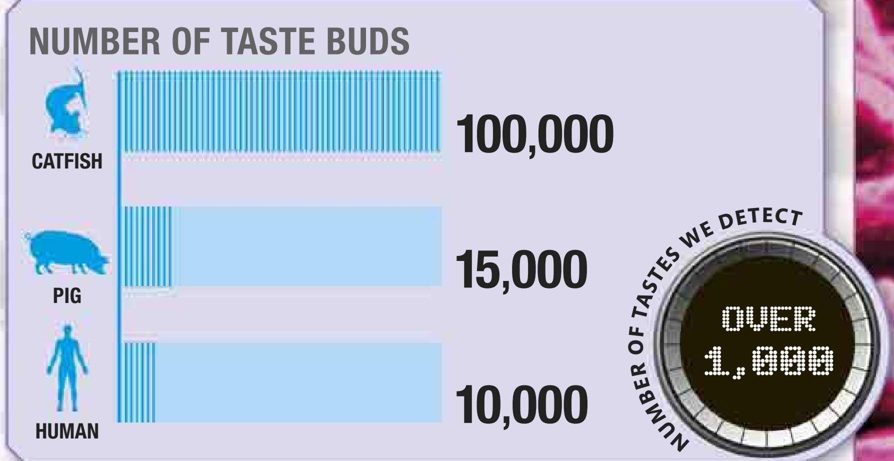
Taste buds send their nerve signals to the taste, or gustatory, area on the brain's outer layer, the cortex. Different taste receptor cells respond to different patterns of flavours. From these thousands of messages per second, the brain works out the overall taste of the food. The tongue can detect five main tastes: sweet, sour, salty, bitter, and savoury (umami). Eighty per cent of the flavour of food is actually detected by our sense of smell.

ON THE TONGUE

Taste receptors

A close look at the tongue shows that its upper surface is covered with hundreds of tiny, variously shaped, bumps called papillae. The papillae grip and move food around the mouth when you chew. Many papillae have much smaller taste buds around their sides or edges. They also contain nerve endings that detect pressure, heat, cold, slipperiness, hardness, and pain. These factors combine with taste and smell in the brain to produce the overall sensation of the food being eaten.

STATS AND FACTS



Food's-eye view

Finger-like papillae (coloured pink on this highly magnified image) are less than 1 mm long. The tongue also has about 200 mushroom-shaped papillae (in blue), each with 5–15 taste buds.

"Taste bud cells live for only 10–11 days before they are replaced"

ON THE SCENT

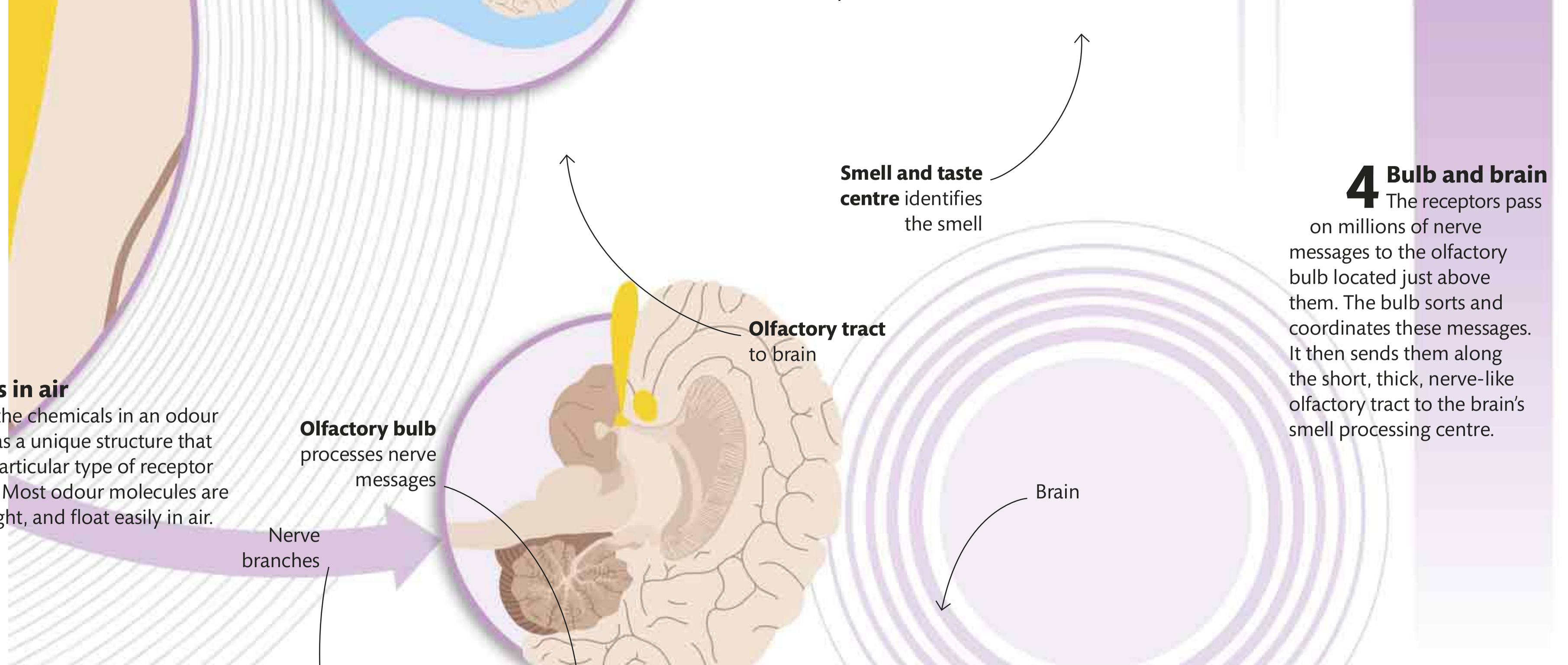
How we smell things

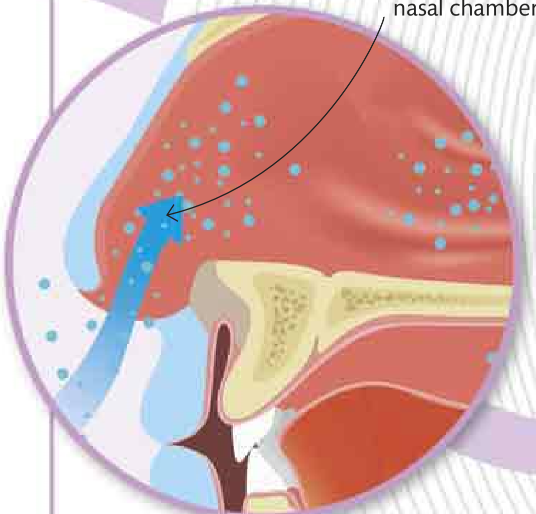
Life without scents, perfumes, odours, and aromas would be very dull. Our supersense of smell can tell apart millions of different odours. It helps us to sniff out harmful gases in the air or the stench of rotten food, and lets us enjoy the aromas of a delicious feast or the perfumes of flowers. The smell, or olfactory, system also has direct nerve connections into parts of the brain that deal with memories and emotions. This is why smells from our past, such as a pine forest or the seashore, can bring back strong feelings and powerful memories.

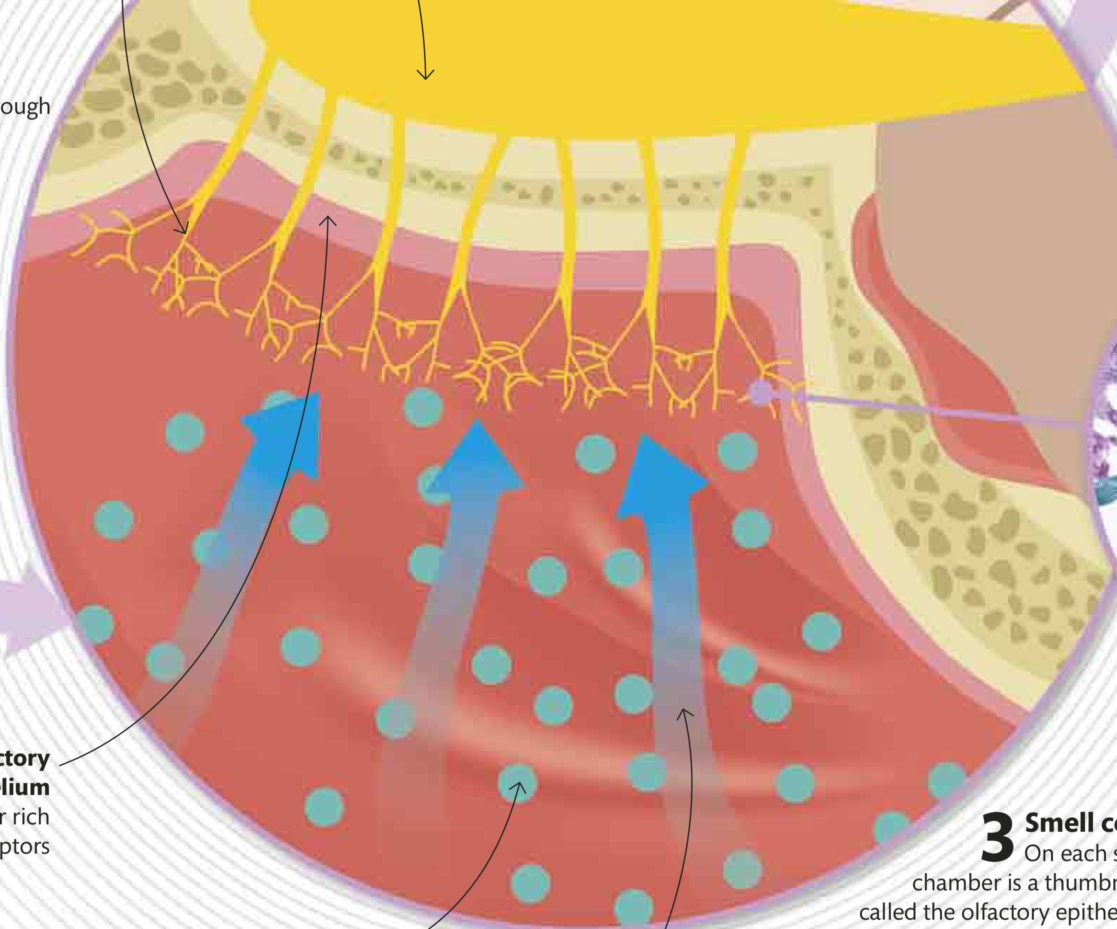
"We have about 20 million smell receptors in our nose"

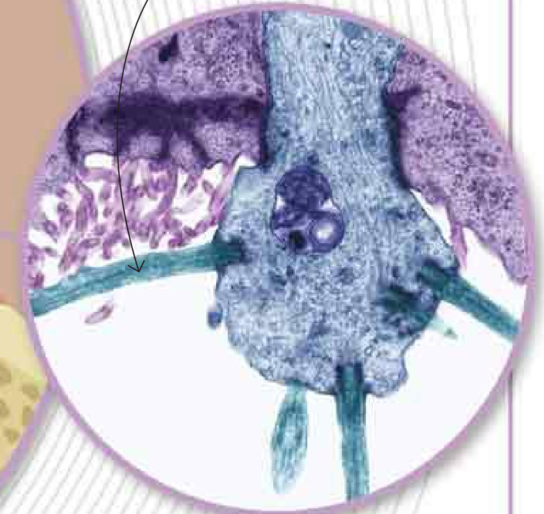
FROM AIR TO BRAIN

As with taste, our sense of smell is based on chemistry. Receptor cells in the nose detect odour molecules floating in the air and send nerve messages to the brain. Unlike taste, smell is a long-distance sense – we can sniff out certain odours from hundreds of metres away.







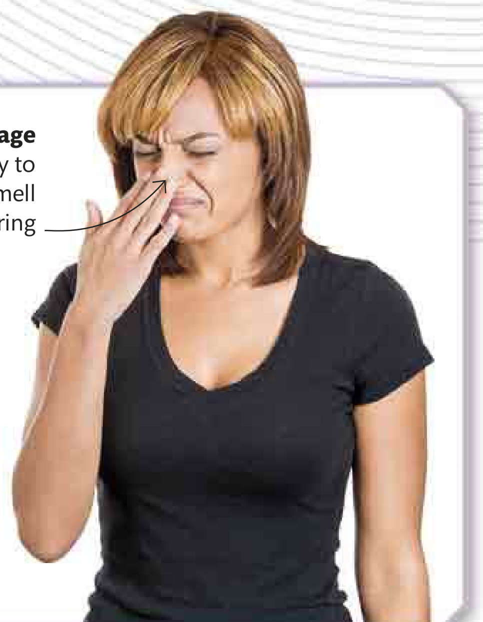


2 Into the nose When you want to smell something, you take a small sniff. This makes air, and with it the odour molecules, swirl into the nasal chamber, the space in the upper part of your nose where the receptor cells are located.

3 Smell cells On each side of the nasal chamber is a thumbnail-sized area called the olfactory epithelium. This contains millions of smell receptors with hair-like endings. When an odour molecule lands on a suitable receptor, it sends a nerve signal to the brain.

WARNING! DANGER!

Certain smells have a fast, direct effect on the body. The foul stench of rotting food, stagnant water, and human digestive waste, or the sharp odour of strong chemicals such as acids, are all quickly identified. They warn of dangers such as germs, infection, and poisoning, and we instinctively wrinkle our nose to avoid them. This partly closes the airways, which reduces damage to the nose's delicate lining from powerful or harmful chemicals in the smell.



STATS AND FACTS

SMELL CELLS

HUMAN 20 million

CAT 70 million

RABBIT 100 million

DETECTION

1 trillion smells can be detected by the human nose

1,000 TYPES OF SMELL RECEPTORS

KEEPING IN TOUCH

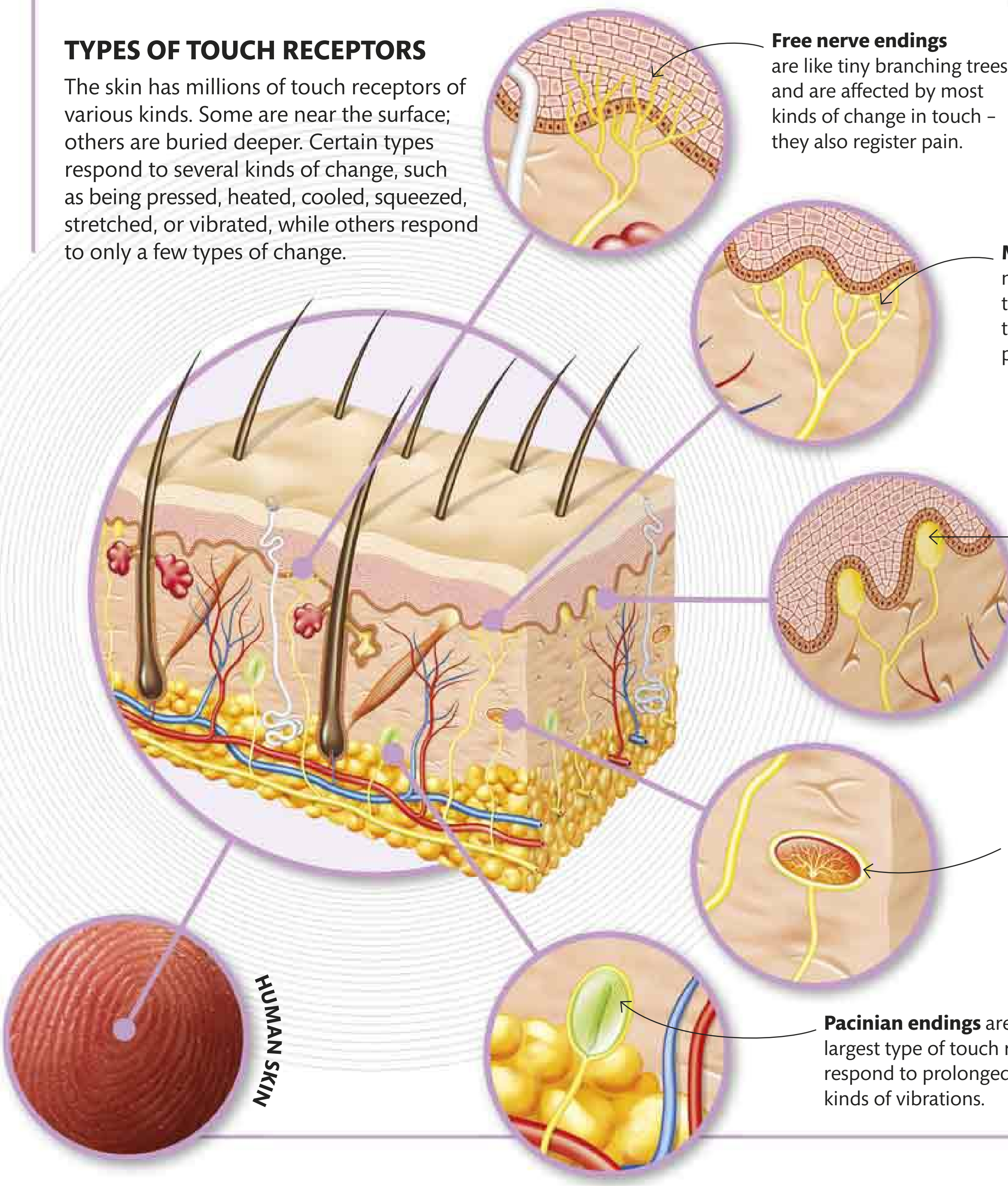
How we feel sensations

Far more than simply sensing contact with something, touch is a super-multi-sense. It begins with a wide range of receptors, or specialized nerve endings in the skin and tissues. Various forms of contact trigger the receptors to send patterns of messages to your brain – thousands every second. From this immense amount of information, the brain works out whether an object is hard or soft, wet or dry, smooth or rough, warm or cold, stiff or bendy, and much more.

> **"If the body was as tall as the Eiffel Tower, the fingertips would be able to feel ridges less than 1mm high"**

TYPES OF TOUCH RECEPTORS

The skin has millions of touch receptors of various kinds. Some are near the surface; others are buried deeper. Certain types respond to several kinds of change, such as being pressed, heated, cooled, squeezed, stretched, or vibrated, while others respond to only a few types of change.



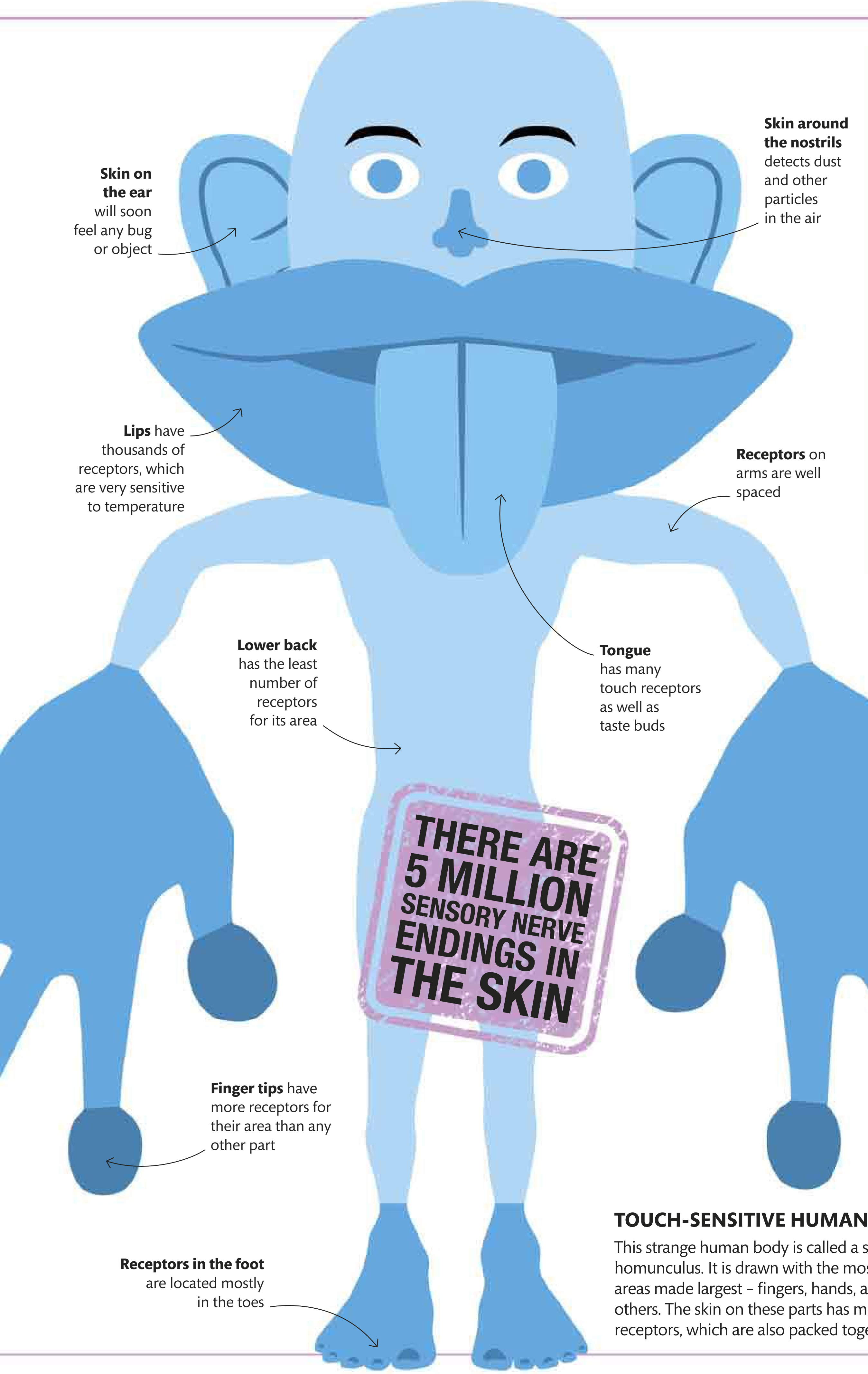
Free nerve endings are like tiny branching trees and are affected by most kinds of change in touch – they also register pain.

Merkel endings are located near the skin's surface and they are especially sensitive to medium levels of touch, pressure, and slower vibrations.

Meissner endings sit just below the epidermis and respond to very light, brief touches as well as faster vibrations.

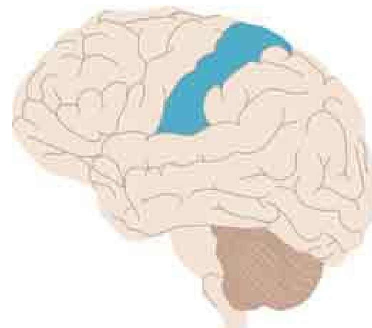
Ruffini endings are sensitive to being stretched and squeezed; they also react to changes in temperature.

Pacinian endings are the deepest and largest type of touch receptor; they respond to prolonged pressure and all kinds of vibrations.



TOUCH ON THE BRAIN

Nerve messages from the skin speed to a strap-shaped area of the brain's surface, called the touch or somatosensory cortex. The uppermost part of it receives information from the feet and legs, then lower down from the arms, hands, and fingers, and near the base, from the face, tongue, and lips. The brain itself cannot feel pain.



SOMATOSENSORY CORTEX

TOUCH-SENSITIVE HUMAN

This strange human body is called a sensory homunculus. It is drawn with the most sensitive areas made largest – fingers, hands, and lips, among others. The skin on these parts has more kinds of touch receptors, which are also packed together more closely.

> “The **fingertips** can feel **tiny bumps** that the **eye** cannot **see**”

FEELING GROOVY

Fingertips

Faced with something new, the body’s immediate instinct, if all is safe, is to feel it with the fingertips. Each finger has an estimated 15,000 touch nerve endings, packed in closest at the tip. Almost no other part of the body is as sensitive. As the fingertip moves over an object, its ridges bend and distort slightly, triggering the touch endings along their edges. The smallest thing you can feel with a single touch is only 0.00002 mm high or 1/5000th the width of a hair.

STATS AND FACTS

FINGERPRINTS

1 in 64,000 MILLION

The chance of two fingerprints matching – more unique than even DNA

AVERAGE DIMENSIONS

0.3 mm Height of a fingertip skin ridge

0.4 mm Width of a fingertip skin ridge

RIDGES PER FINGERTIP

120–150

Remarkable ridges

Up close, the skin on the fingertips looks like a chain of mountains. The ridges and grooves help to grip and also sense the tiniest of variations in a surface. The round pits along the ridges are sweat pores.

THAT HURTS!

How we feel pain

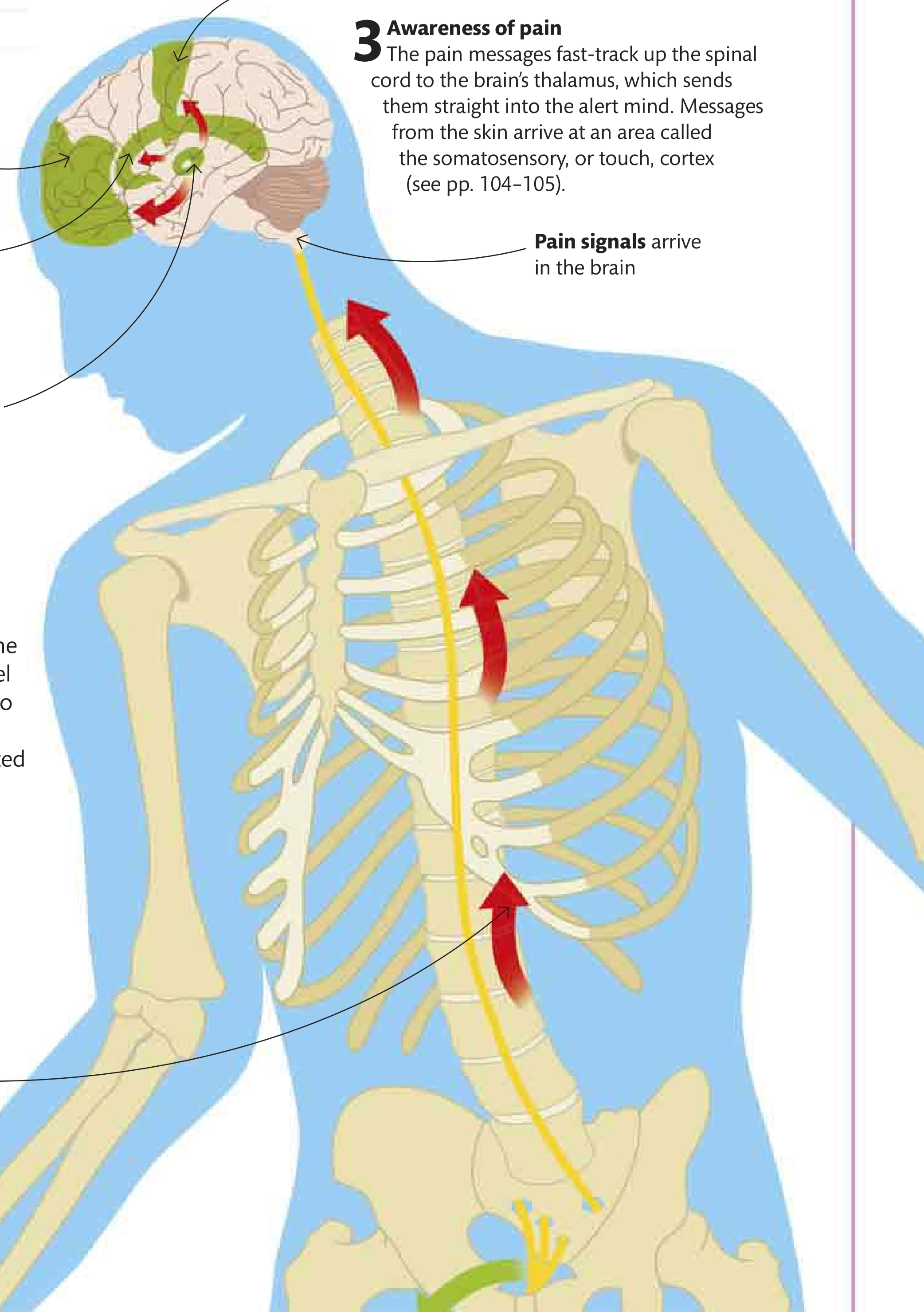
Pain is certainly not welcome, but it is definitely useful. It is an early warning that some part of the body is in danger of being damaged. The natural response is to move away from the cause of the pain and rest the injured area until it heals. Most kinds of touch sensor in the skin can send pain signals to the brain. There are pain sensors inside the body as well – in joints, muscles, main blood vessels, intestines, and even bones.

RUB IT BETTER

It can help to stroke or rub a part that hurts. Rubbing produces hundreds of signals from the other touch sensors in the area. These swamp the brain and sidetrack its attention, so that it feels the rubbing more than the pain.

PAIN PATHWAYS

The more touch sensors are squeezed, heated, or frozen, the more nerve signals – of different patterns – they send to the brain. The messages travel along nerve fibres at up to 50 m (160 ft) per second. In the brain they are routed straight to the conscious awareness, so the mind can take urgent action.



3 Awareness of pain
The pain messages fast-track up the spinal cord to the brain's thalamus, which sends them straight into the alert mind. Messages from the skin arrive at an area called the somatosensory, or touch, cortex (see pp. 104–105).

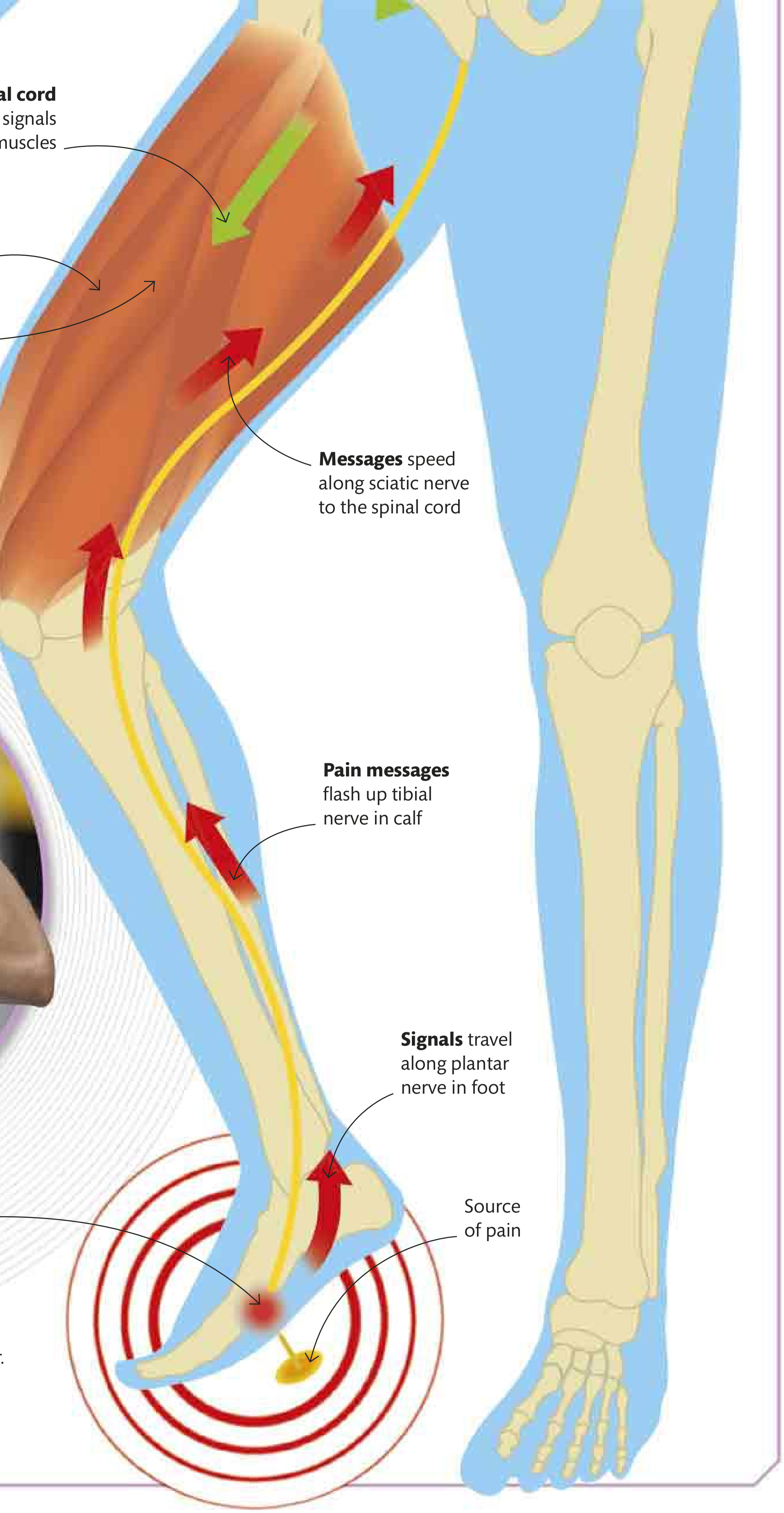
SOME LIKE IT HOT

Spicy foods often taste hot. But they are not truly burning the mouth and tongue with heat. A substance called capsaicin in chillies and similar spices can trigger the nerve endings that usually detect warmth and pain. So although capsaicin is at body temperature in the mouth, the brain registers a fiery feeling.

PAIN, STRESS, AND STRAIN

Pain levels vary – even in the same person at different times. How painful an injury feels often depends on our physical and mental state when it happens. Someone who is tired usually feels pain more deeply than a person who is full of energy.

REACTION TIME TO PAIN IS 1/15 OF A SECOND



2 Auto-reaction The signal reaches the spinal cord, which triggers a reflex link to the motor nerves that control the leg muscles. These contract to jerk the foot away from the site of the pain.

1 Cause of pain A pin prick penetrates the skin, triggering touch sensors called free nerve endings. Further damage to underlying muscles registers a split-second later.

4

POWER SYSTEMS

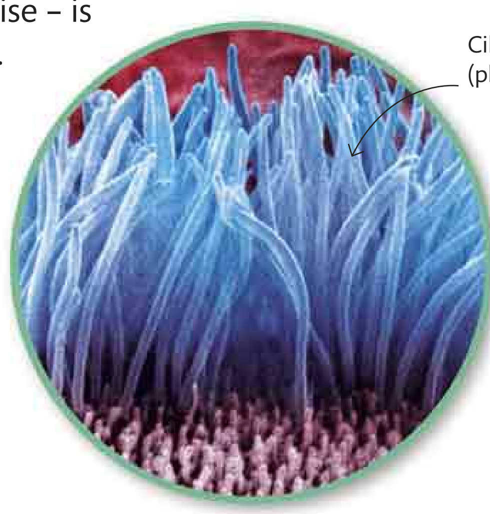
Regular, reliable, and dependable, every second the lungs breathe, the heart beats, and the pulse throbs as the blood flows. The rest of the body relies on these supersystems never to pause or lose their power.

BREATHING MACHINE

Lungs and airways

2,500 ALVEOLI WOULD FIT ON A FINGERNAIL

The body can survive for a while without food, and for a lesser time, even without water. But the need for oxygen is constant and critical. This gas is in the air all around. Yet its need is so urgent that without it, some body parts, such as the brain, become damaged in minutes. After a few more minutes, many cells and tissues start to die. The lungs are where oxygen from the air we breathe in enters the blood. Also, waste carbon dioxide – which could poison the body if its levels rise – is removed from the blood and breathed out.



CLEANING YOUR AIR

The windpipe and main airway linings have millions of micro-hairs called cilia in a coating of sticky mucus. The mucus traps dirt and germs. The cilia bend to and fro to move these up to the throat for coughing out or swallowing.

"The surface area of the lungs is 35 times larger than that of the skin"

There are 2,414km (1,500 miles) of airways in the lungs

STATS AND FACTS

TOTAL VOLUME OF BOTH LUNGS

5-6 litres (11–13 pints) ADULT MALE

4-5 litres (9–11 pints) ADULT FEMALE

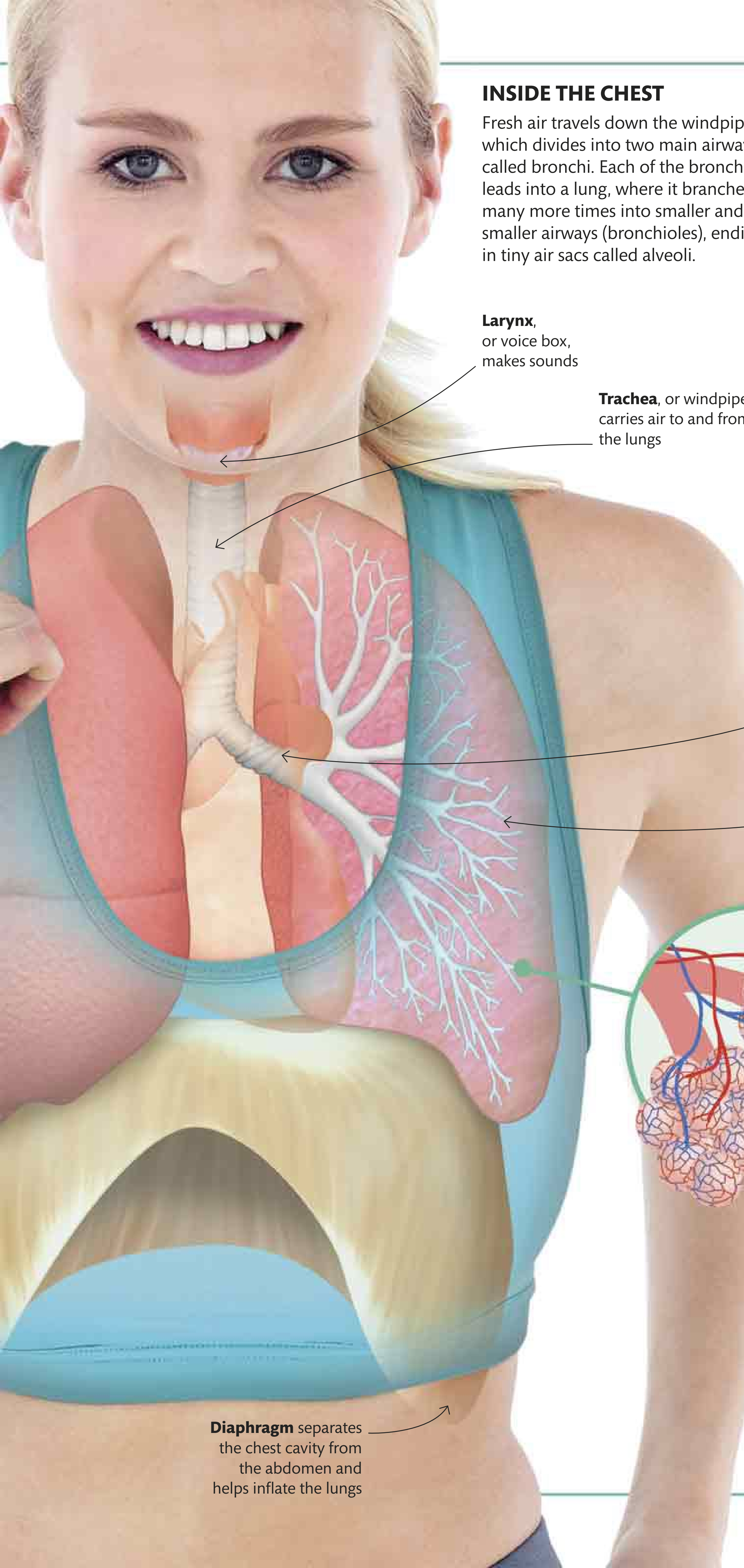
BREATHING CAPACITY

You take about **30,000** breaths per day, the same as blowing air into 2,000 balloons

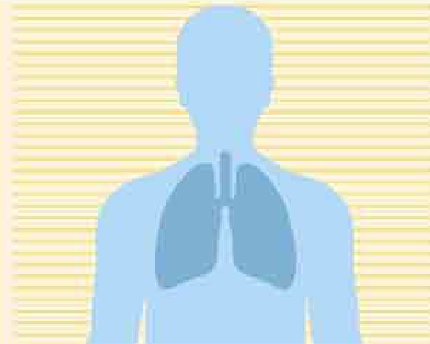
AIR SACS IN BOTH LUNGS: **600 MILLION**

INSIDE THE CHEST

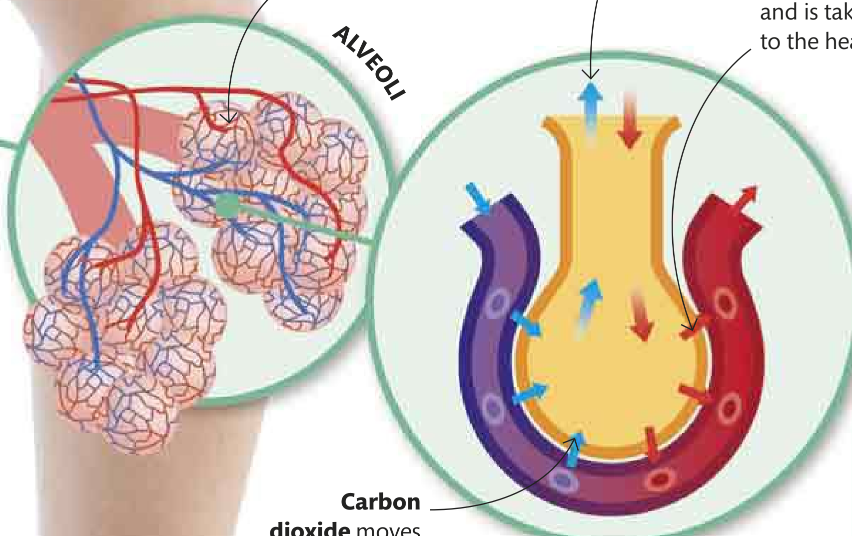
Fresh air travels down the windpipe, which divides into two main airways called bronchi. Each of the bronchi leads into a lung, where it branches many more times into smaller and smaller airways (bronchioles), ending in tiny air sacs called alveoli.



AT A GLANCE



- **SIZE** Height of each lung 30 cm (12 in), weight about 0.6 kg (1.3 lb)
- **LOCATION** Fill 90 per cent of the chest, along with the heart and main blood vessels
- **FUNCTION** Pass oxygen from air to blood, carbon dioxide from blood to air; provide air pressure for vocal sounds, coughs, and sneezes



AIR SACS

Each tiny air sac, or alveolus, is surrounded by a network of the smallest blood vessels, capillaries. Oxygen in the air can easily pass through the thin alveolus and capillary walls into the blood, while waste carbon dioxide follows the opposite route – from the blood to the alveolus.

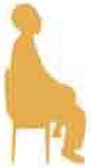
TAKE A DEEP BREATH

How the lungs work

Your lungs are never still. Every few seconds, day and night, they expand, pushing out the chest. This draws fresh, oxygen-rich air in through the mouth and nose, down the windpipe, and into the airways. Right after that, the lungs become smaller, or contract, to push out the stale air, which now contains waste carbon dioxide gas. Breathing in needs the power of the rib muscles and a sheet of muscle under the lungs, called the diaphragm to pull air in. Breathing out needs hardly any muscle effort at all.

BREATHING RATES

Busy muscles need more oxygen. The brain tells the diaphragm and rib muscles to work harder and faster, and increase the in-out air flow of 6 litres (6 quarts) per minute at rest, by up to 20 times when exercising.



RESTING
10–20
BREATHS PER MINUTE

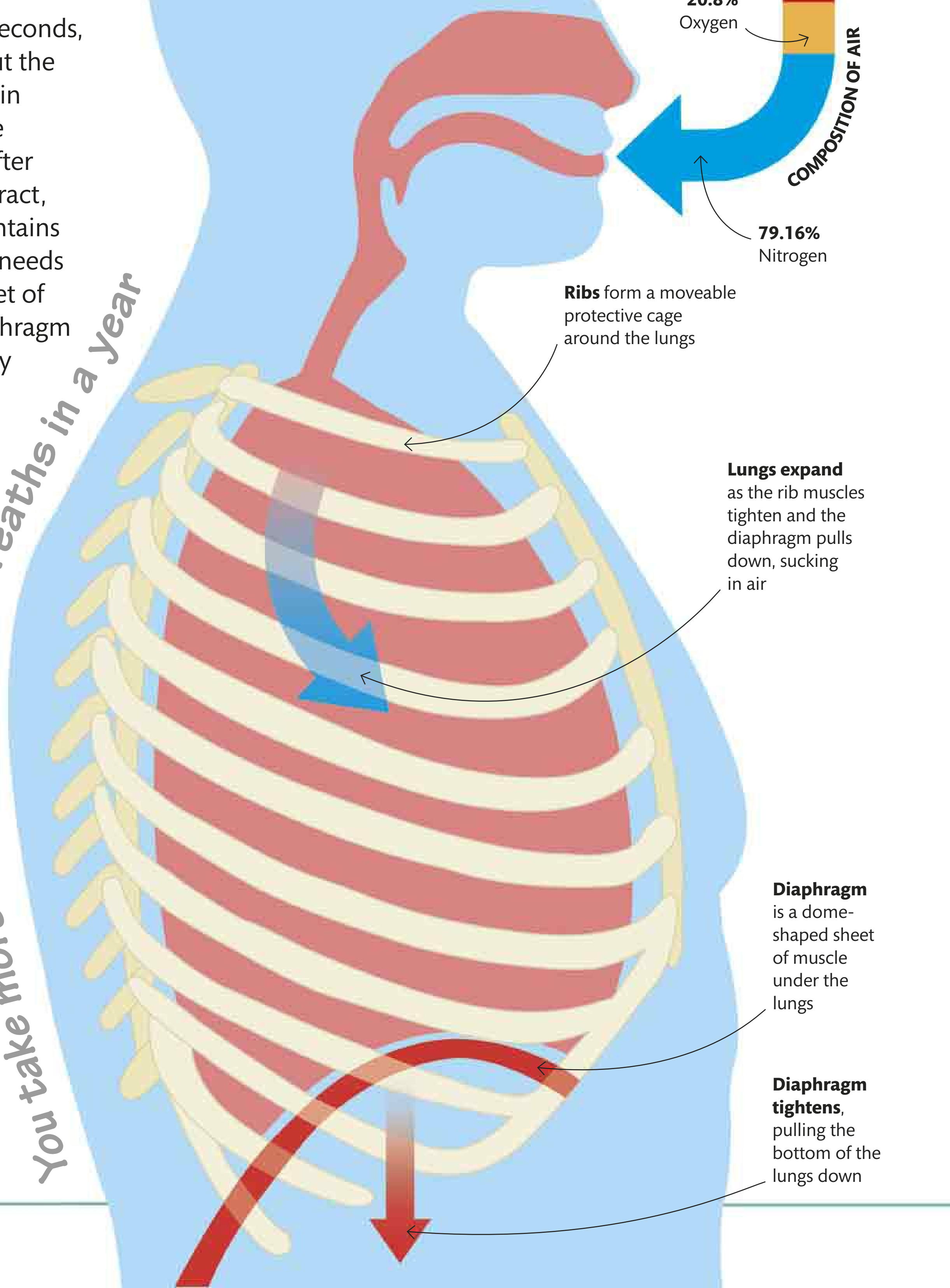
EXERCISING
30–40
BREATHS PER MINUTE

INTENSE RUNNING
50–60
BREATHS PER MINUTE

You take more than 10 million breaths in a year

BREATHING IN

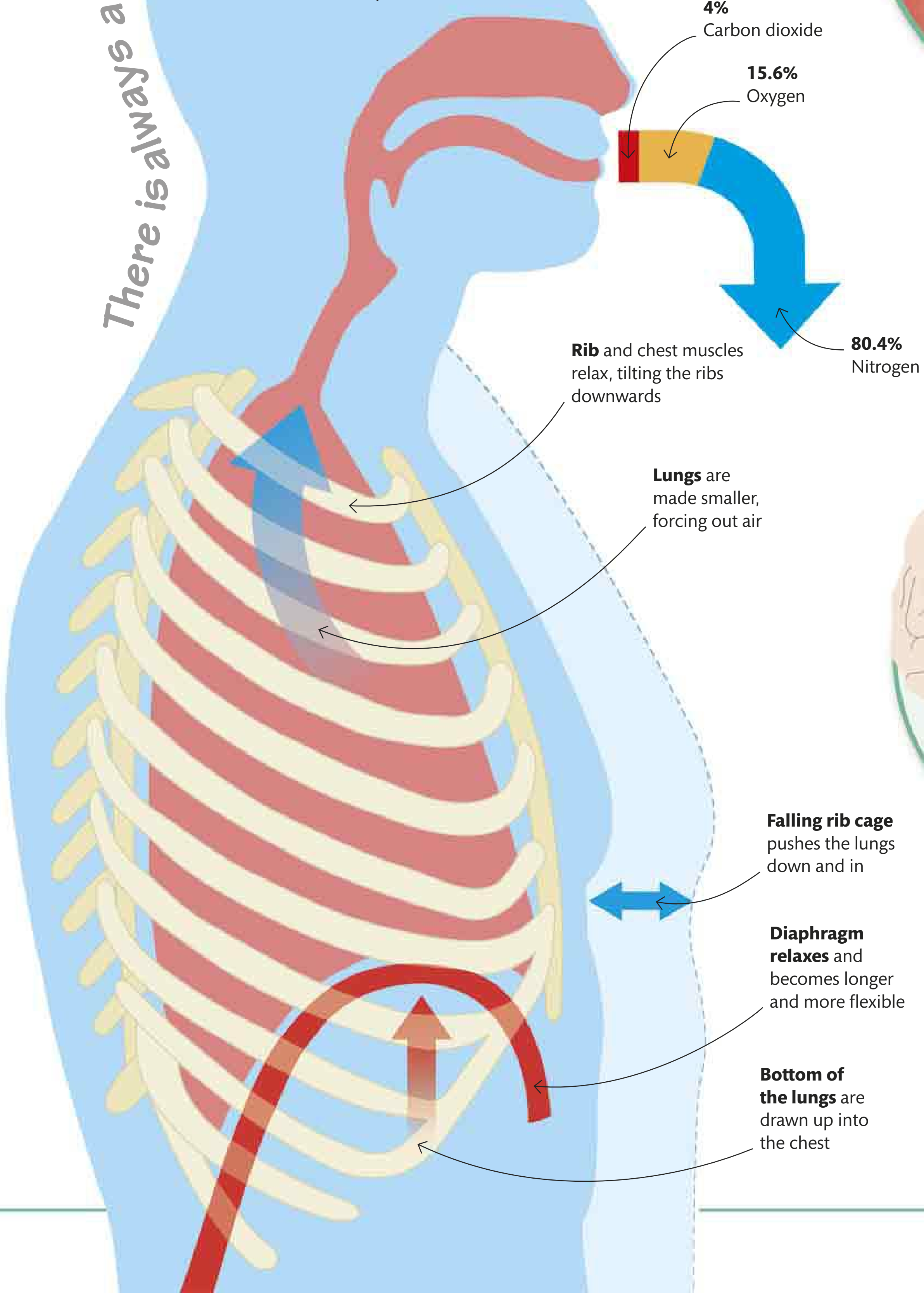
Movement of the diaphragm and rib muscles allows the lungs to stretch out, much like a squashed sponge. This lowers the air pressure inside the lungs, so air flows in from the outside.



There is always a litre (2 pints) of air in your lungs

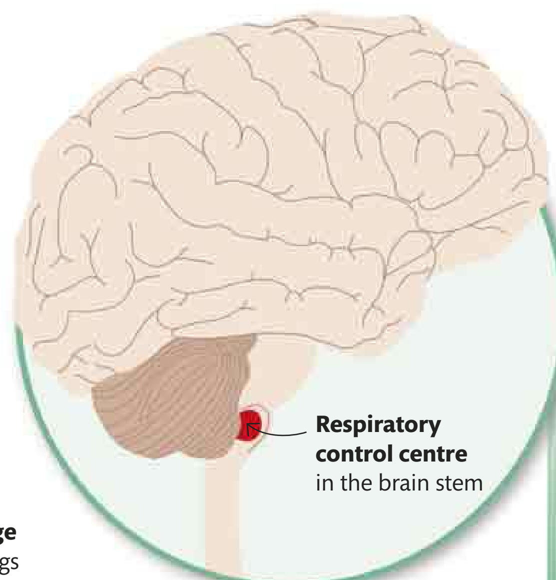
BREATHING OUT

When the diaphragm and rib muscles relax, the stretched lungs spring back to their smaller size. This pushes air out of the lungs, up the windpipe, and out of the body.



UNDER PRESSURE

The breathing system can produce enough air pressure to push water more than 2 m (6 ft) up a narrow tube – or blow up a party balloon! To increase pressure for a big puff, the shoulder, back, and abdomen muscles help the ribs and diaphragm.



CONTROLLING BREATHING

Breathing, or respiration – as with other similar automatic actions – is controlled in the brain stem (lower part of the brain). It receives information about levels of carbon dioxide and oxygen in the blood and sends messages to the rib and diaphragm muscles accordingly.

HUMAN SUB

Freediving

Deep-water divers battle against the most powerful of human instincts – to breathe. Specialized nerve endings monitor oxygen and carbon dioxide levels in the blood, especially in the arteries going to the brain. Sensors in the lower brain monitor the fluid in and around the brain. When carbon dioxide is too high, they tell the brain's breathing control centre to make breathing faster and deeper to take in more oxygen. The challenge is to return to the surface before giving in to that instinct.

STATS AND FACTS

MAXIMUM DIVE DEPTHS

214 m (702 ft) HUMAN	390 m (1,280 ft) BOTTLENOSE DOLPHIN	564 m (1,850 ft) EMPEROR PENGUIN

RECORD SWIM

280 m (919 ft)
The longest single-breath underwater swim by a person

HOLD YOUR BREATH

11 minutes
The longest unaided breath-hold

Plumbing the depths

Freedivers use breathing techniques that help them hold their breath longer than usual. They learn to recognize when carbon dioxide is building up, and to relax their muscles so they use less oxygen.

“At 10 m (33 ft) below the surface, water pressure collapses the lungs to just half their normal volume”

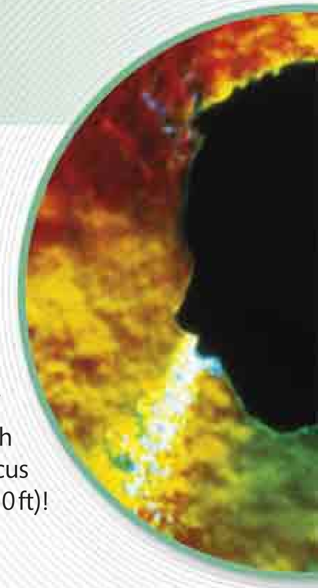
SCREAM AND SHOUT

Making sounds

The breathing, or respiratory, system does more than just take in oxygen and remove carbon dioxide. It can whisper, whistle, wail, speak, shout, scream, laugh, cry, and make many other fantastic sounds. Most come from the voice box, or larynx, in the neck. The system also makes noises when protecting itself from breathed-in dust and germs – explosive coughs and sneezes.

SNEEZE AND COUGH

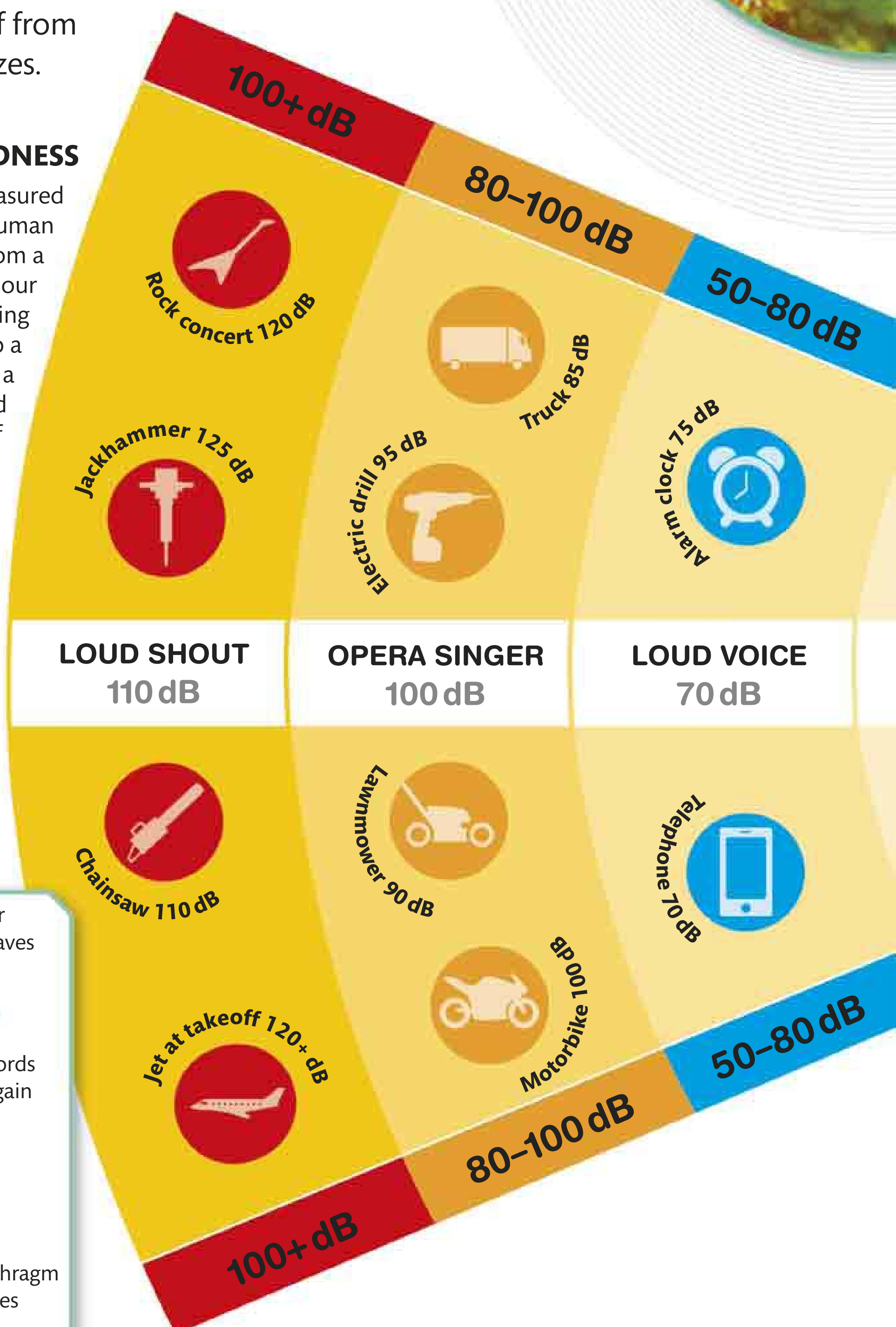
A sneeze is a sudden blast of air out of the nose that blows away drops of mucus and dust at speeds of up to 160 km/h (100 mph). Coughing is used to clear the lower airways and windpipe, rattling the vocal cords as it comes out of the mouth. The air travels up to 72 km/h (45 mph) and sprays tiny drops of mucus over a distance of 3 m (10 ft)!



“Some snorers are louder than a low-flying jet, reaching 110 decibels”

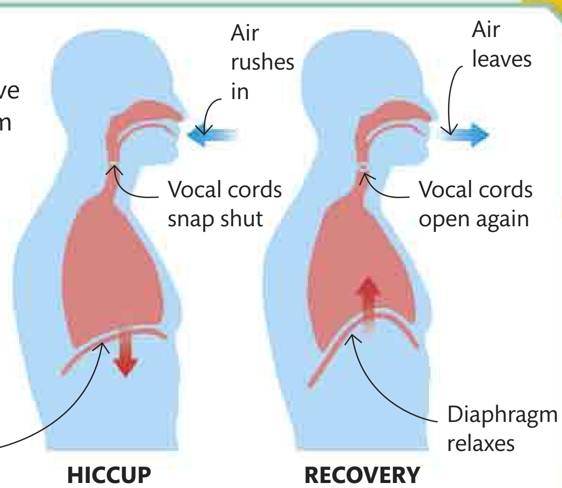
COMPARING LOUDNESS

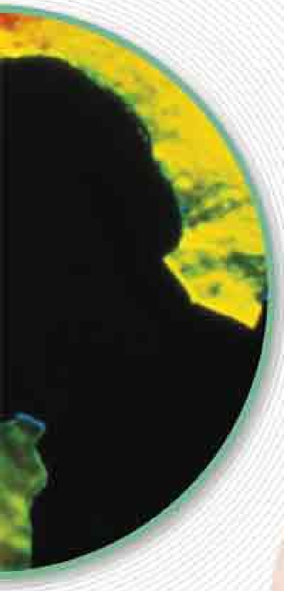
Loudness, or volume, is measured in decibels (dB). The human voice can range from a whisper – just above our lower range of hearing of 0–5 dB – to a shout as loud as a chainsaw: a sound that would hurt if it was right by your ear.

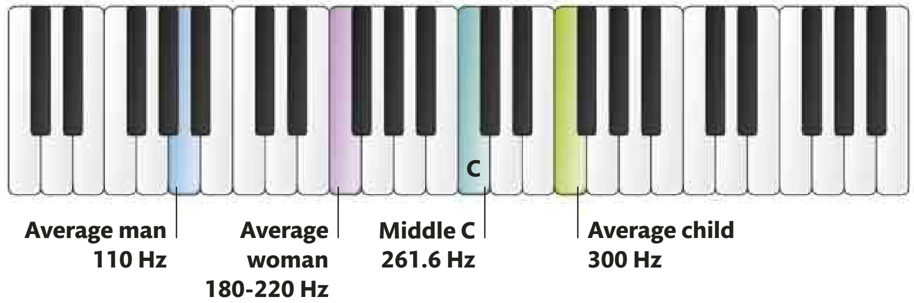


HICCUPS

Hiccups happen when nerve signals make the diaphragm muscle contract sharply. There are many causes – from eating or drinking too much or too fast, to a sudden fright or cough. There are many remedies, too – from sipping a drink to another sudden fright!





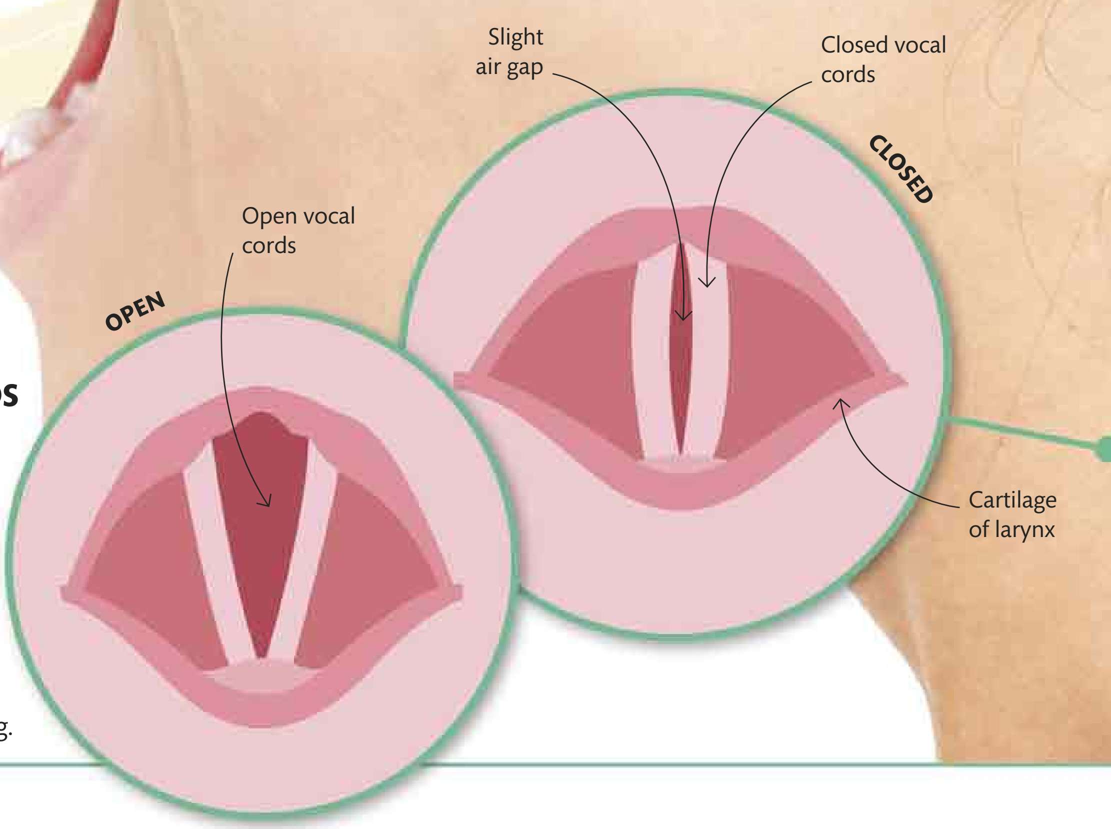


RANGE OF THE HUMAN VOICE

The voice goes from low to high pitch (frequency, measured in Hertz, Hz) when muscles stretch the vocal cords so they vibrate faster. A child's voice is higher, with folds only 6–10 mm (¼–½ in) long. In an adult female, they are 12–18 mm (½–¾ in) long. In a male, the voice "breaks" in the teen years as the folds become thicker and 17–25 mm (¾–1 in) long.

VOICE PITCH

- **MEN ≈ 110 Hz**
- **WOMEN ≈ 180–220 Hz**
- **CHILDREN ≈ 300 Hz**



VOCAL CORDS

When you speak, you activate your vocal cords, which are two strong, shelf-like folds in the walls of the larynx, or voice box. Muscles pull them close together so passing air makes them shake or vibrate fast. The noise of the vibrations is made louder by the throat, mouth, and nose. The cords relax and open fully when you are not speaking.

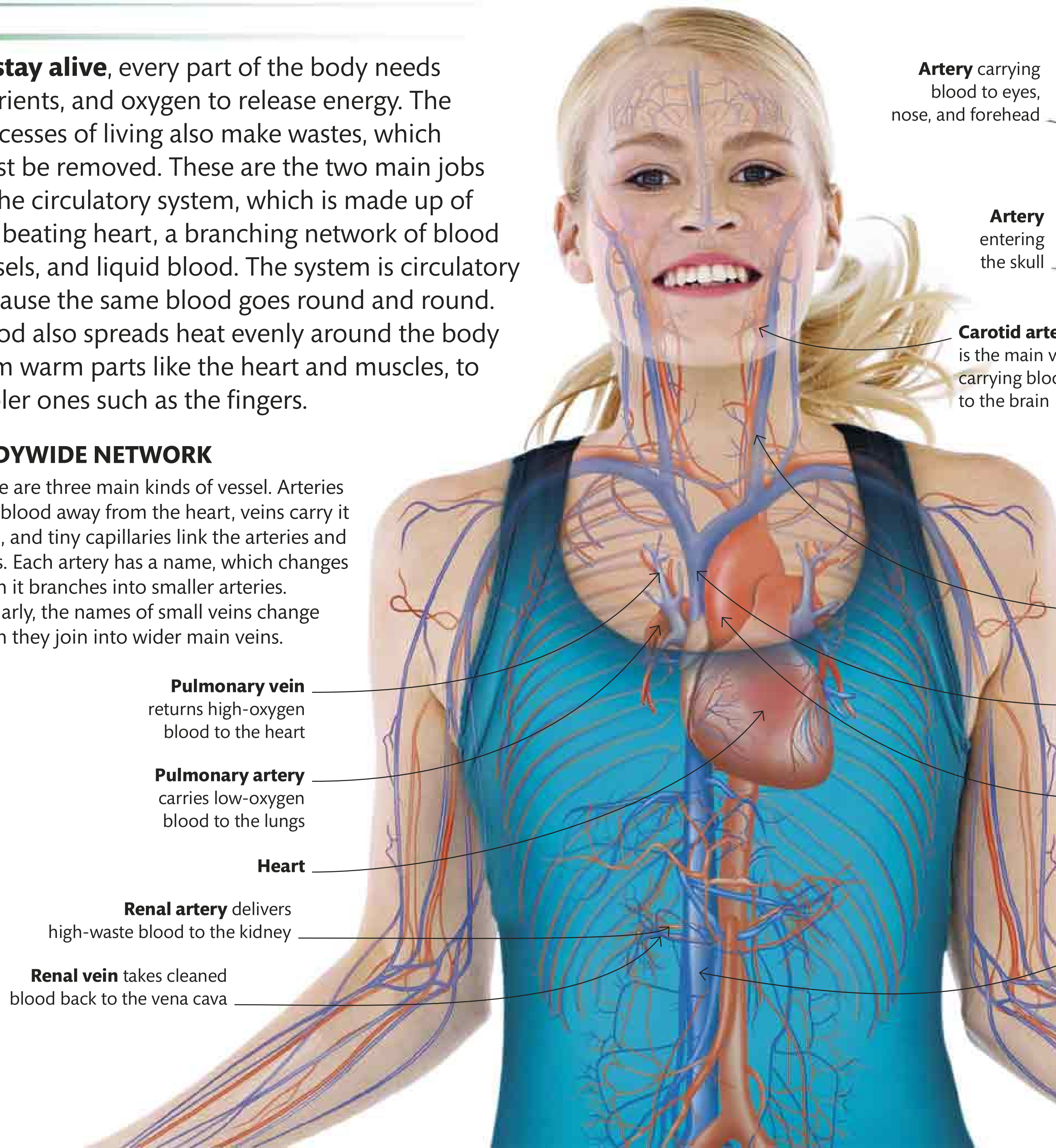
CIRCULATION CENTRAL

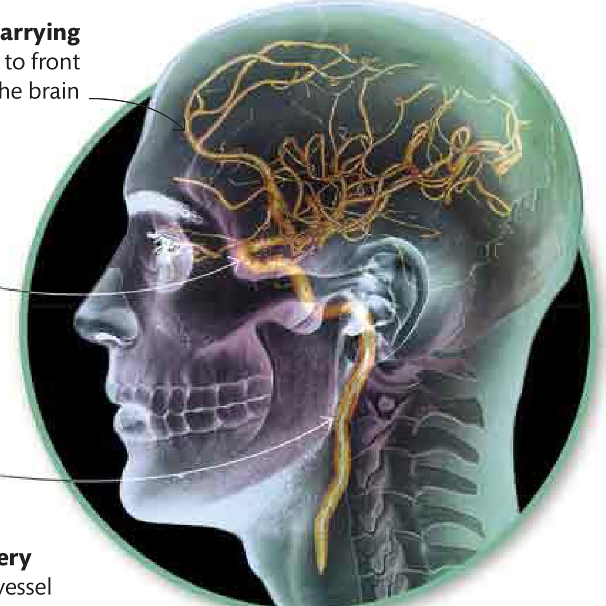
How blood travels

To stay alive, every part of the body needs nutrients, and oxygen to release energy. The processes of living also make wastes, which must be removed. These are the two main jobs of the circulatory system, which is made up of the beating heart, a branching network of blood vessels, and liquid blood. The system is circulatory because the same blood goes round and round. Blood also spreads heat evenly around the body from warm parts like the heart and muscles, to cooler ones such as the fingers.

BODYWIDE NETWORK

There are three main kinds of vessel. Arteries take blood away from the heart, veins carry it back, and tiny capillaries link the arteries and veins. Each artery has a name, which changes when it branches into smaller arteries. Similarly, the names of small veins change when they join into wider main veins.





BLOOD TO THE BRAIN

This medical scan shows the main artery to the brain, the internal carotid. It passes up the neck and into the skull, and then divides into smaller branches that take blood to all brain parts.

CHECKING YOUR PULSE

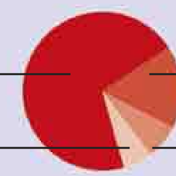
As each heartbeat forces blood into the arteries, they bulge. Feel this bulging, called the pulse, on the inside of your wrist, where the radial artery is just under the skin.

"All the blood vessels laid end to end would stretch twice around the world"

The heart beats around 100,000 times each day

STATS AND FACTS

BLOOD DISTRIBUTION



BLOOD VOLUME

5–6 LITRES

(9–11 pints) Amount of blood in an adult male, about the same as

24 x MEASURING JUG

BLOOD AS PART OF BODY WEIGHT

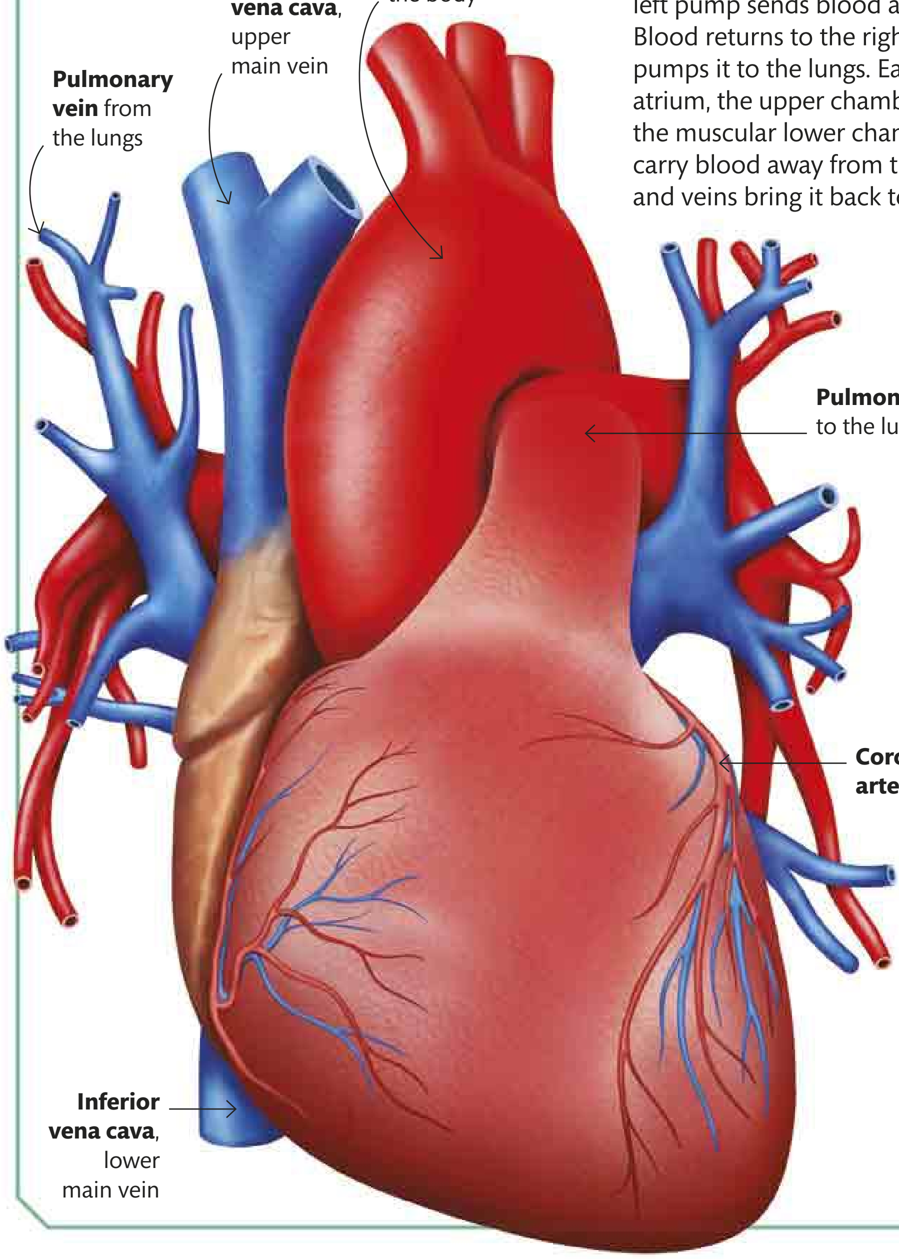
9 PER CENT

BODY PUMP

The heart

"Each **day** the **heart** creates **energy** that could **power** a **truck** for **32 km** (20 miles)"

No machine can match the heart's outstanding abilities. It works every second, day and night, for 70, 80, or even 100 years. It constantly maintains and mends itself. It responds to the body's needs by continually adjusting the amount of blood it pumps with each beat and its beating speed. This means that while the heart conserves energy during sleep, it can increase its blood output by five times during strenuous exercise.

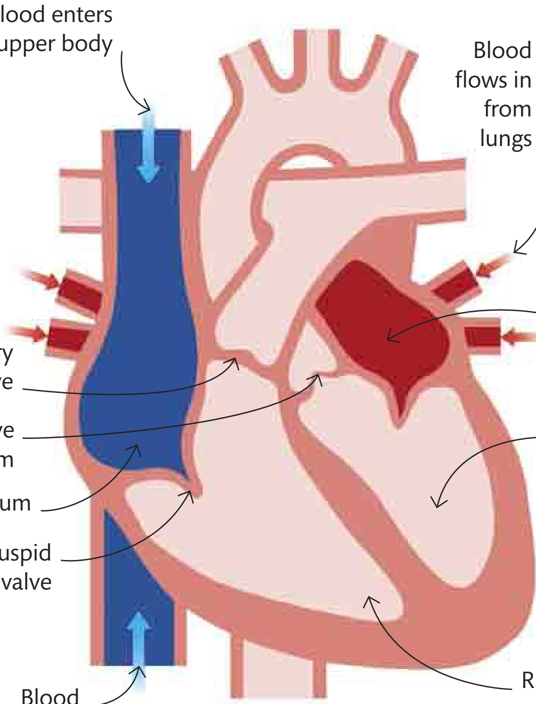


PARTS OF THE HEART

The heart consists of two pumps. The left pump sends blood around the body. Blood returns to the right side, which pumps it to the lungs. Each pump has an atrium, the upper chamber, and a ventricle, the muscular lower chamber. Arteries carry blood away from the ventricles, and veins bring it back to the atria.

HOW THE HEART BEATS

The heart contracts its muscular walls to squeeze the blood inside, forcing it out into the main arteries. There are four heart valves, two in each side. These tough, flexible flaps push open easily to let blood flow the correct way, then flip shut to stop any backflow.

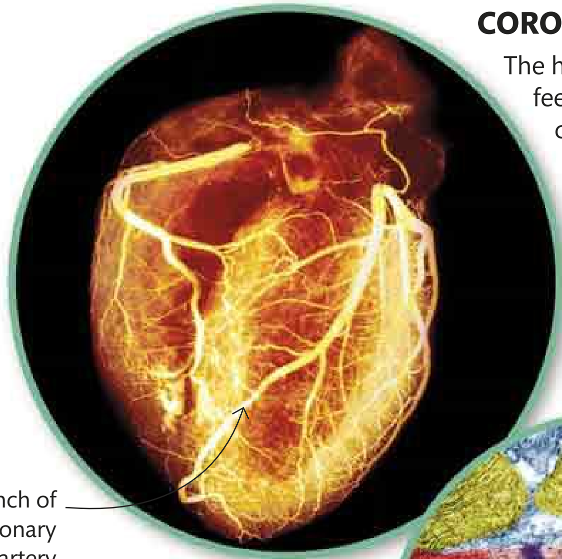


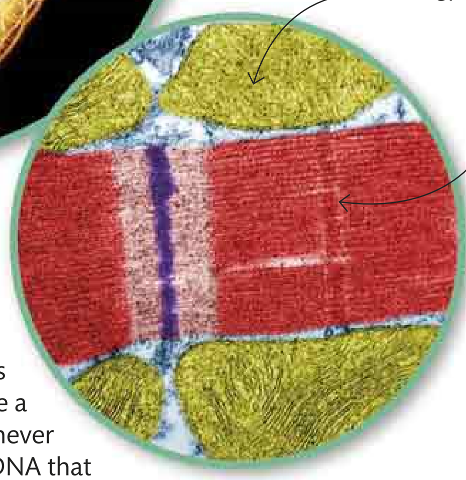
1 Blood flows in

As the heart's muscular walls relax, blood oozes at low pressure from the main veins into the upper chambers (atria). Blood from the body, containing little oxygen, enters the right atrium. Blood carrying oxygen from the lungs enters the left atrium, through the pulmonary veins.

CORONARY SUPPLY

The heart has its own blood supply to feed it with oxygen, through the coronary arteries. They branch from the start of the aorta (the main blood vessel), loop over the heart's surface, and go down into the thick muscles of the heart walls.





HEART MUSCLE

The heart's walls are made of a special muscle called cardiac muscle, or myocardium. It contains many subunits called mitochondria, which provide a plentiful supply of energy, so the heart never tires. Mitochondria contain special DNA that regulates oxygen and energy in most body cells.

STATS AND FACTS

RESTING HEART RATE

BLUE WHALE — 7–10 beats per minute

HUMAN — 60–70 beats per minute

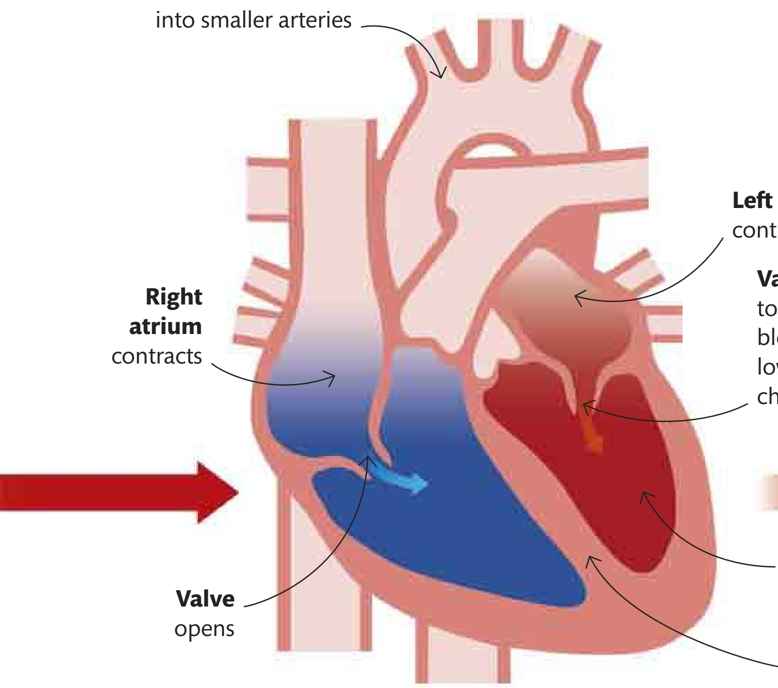
CHICKEN — 250–300 beats per minute

HEART RATE (in bpm)

50–60 SLEEPING

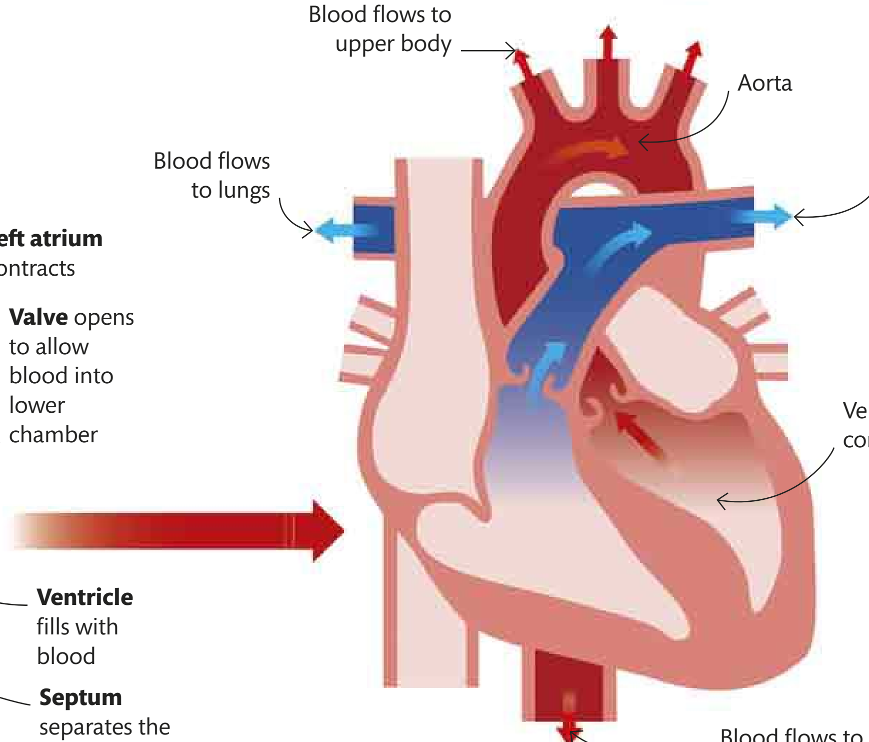
170–200 RUNNING

THE HEART BEATS 100,000 TIMES PER DAY



2 Upper to lower

The walls of each upper chamber (atrium) tighten or contract to push blood through a valve into the lower chambers (ventricles). The ventricle walls are still relaxed so they stretch and bulge as the blood comes in. A wall in the middle of the heart, the septum, keeps the two sets of blood separate.



3 Blood flows out

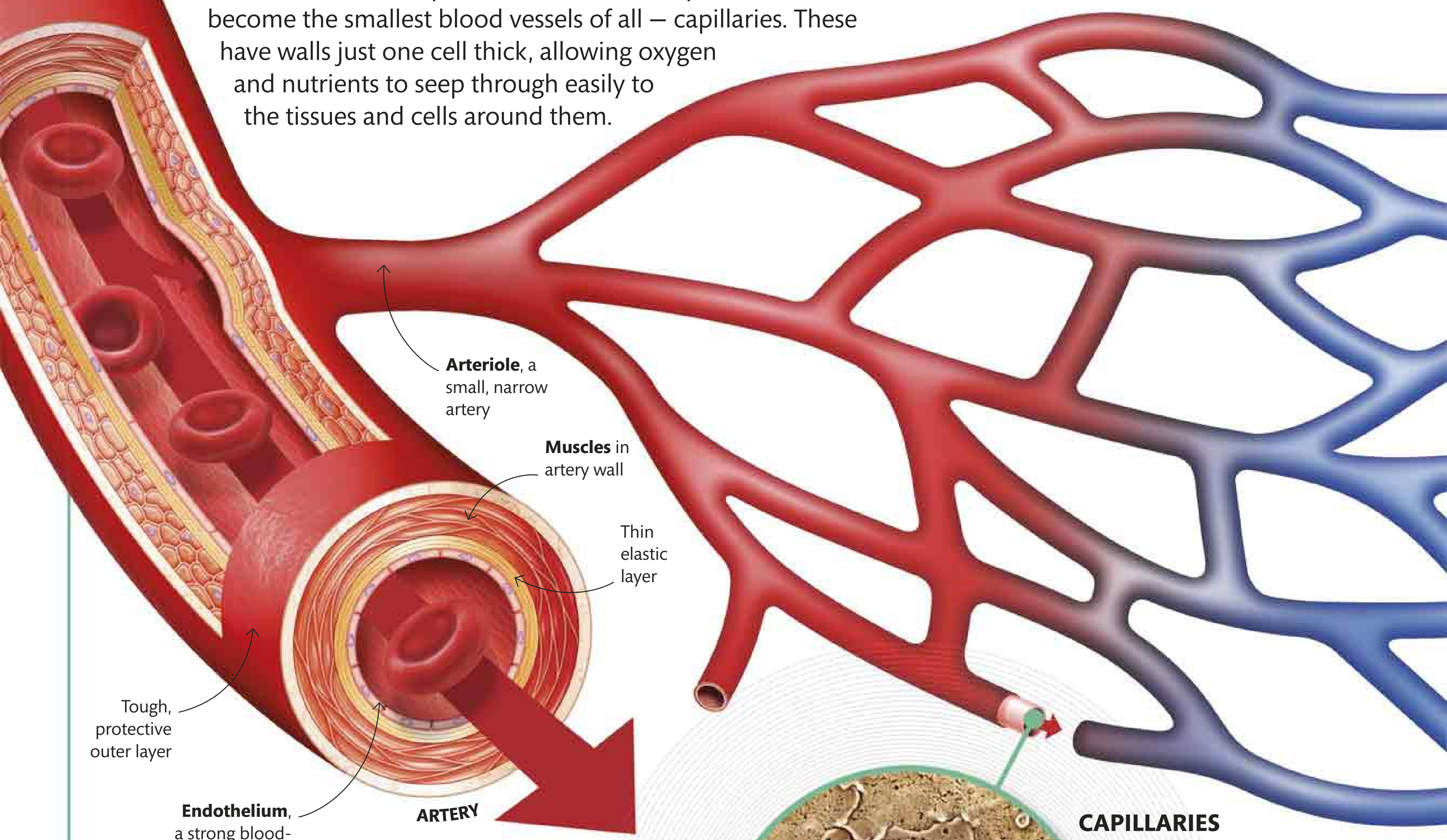
The muscular walls of the ventricles squeeze to force blood through valves into the arteries. The aorta (main artery) takes blood rich in oxygen from the left ventricle to the body, while the pulmonary arteries from the right ventricle carry blood with low oxygen levels to the lungs.

DOORSTEP DELIVERY

Blood's network

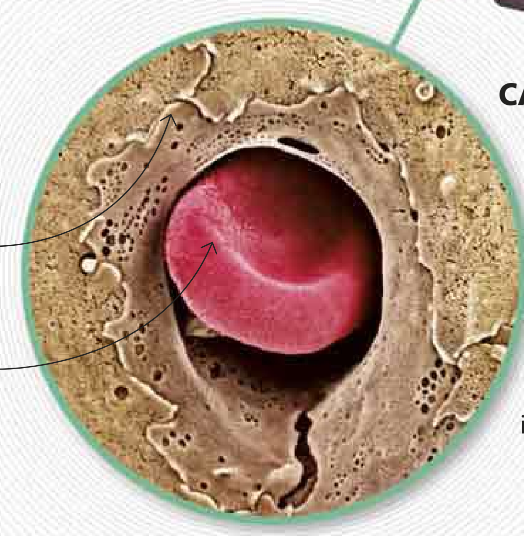
THERE ARE 5 MILLION RED BLOOD CELLS IN A DROP OF BLOOD

With each thumping beat, high-pressure blood surges out of the heart into the main arteries. As these divide, each branch heads to a major organ, such as the liver, kidneys, brain, or muscles. Here the artery branch divides many more times, sending blood along its narrower, thinner branches, deep into the tissues. Finally the branches become the smallest blood vessels of all – capillaries. These have walls just one cell thick, allowing oxygen and nutrients to seep through easily to the tissues and cells around them.



ARTERIES

These vessels have a strong inner lining and thick walls that contain stretchy fibres, so the artery can bulge with each pulse of high-pressure blood. The walls have muscles that contract to make the artery narrower and reduce blood flow, or relax to widen it and allow the blood to flow faster.



CAPILLARIES

These micro-vessels divide and join many times in just a few millimetres, forming a web. Substances such as oxygen and sugars seep out of their thin walls into the surrounding cell as waste, such as carbon dioxide, and spent energy products seep in to be carried away.

PERCENTAGE OF BLOOD FLOW

	AT REST	DURING EXERCISE
MUSCLES	20	75
BRAIN	18	5
HEART	4	5
LIVER	25	2
KIDNEYS	20	2
SKIN	5	3

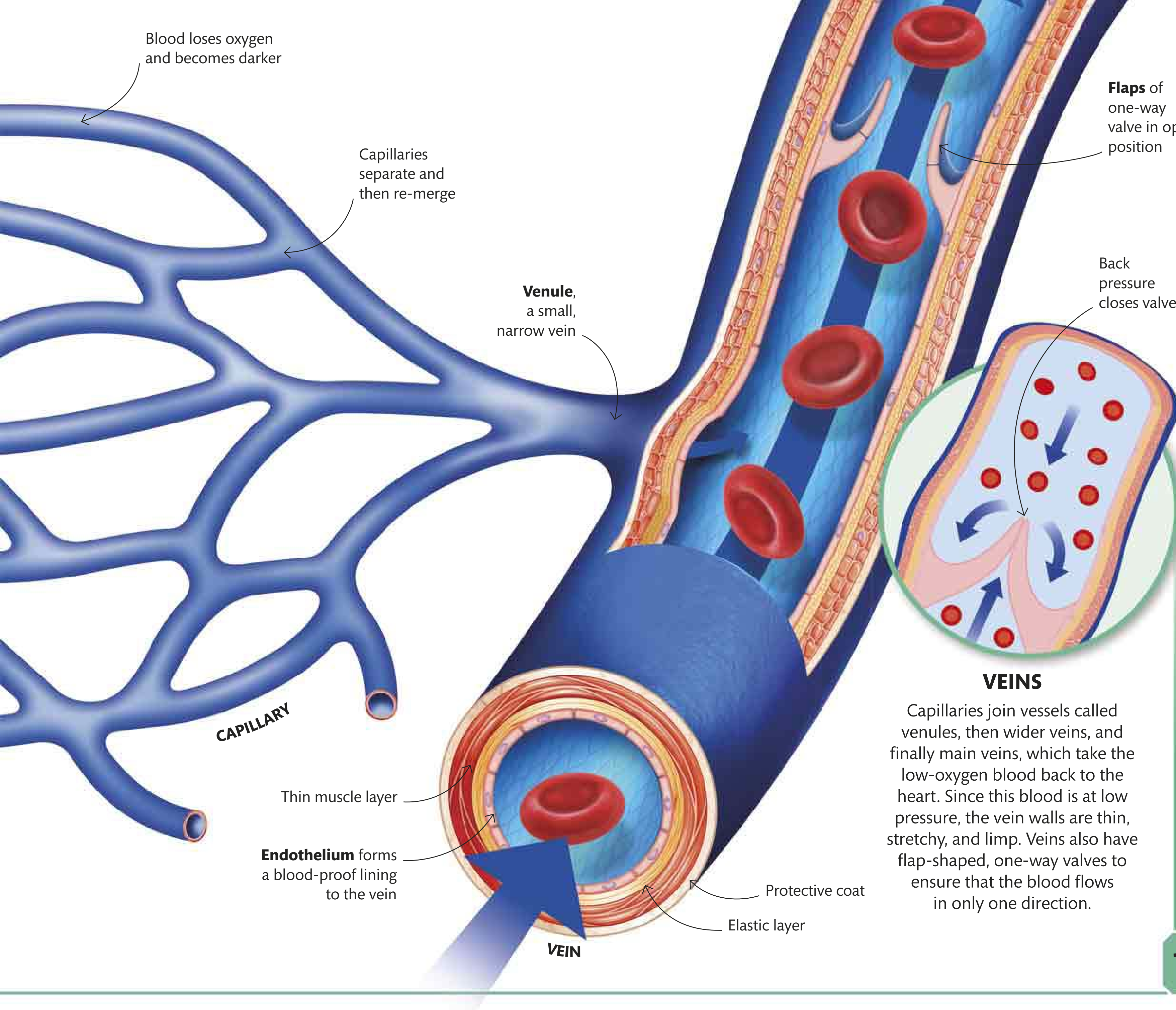
VARIED DEMANDS

The brain automatically sends nerve signals to the artery wall muscles, telling them whether to widen or tighten. During exercise, as muscles need more blood, their arteries widen while those to less busy parts, such as the guts, become narrower.

KEY

AT REST
Heart output 5 litres (9 pints) per minute

DURING EXERCISE
Heart output 25 litres (45 pints) per minute



VEINS

Capillaries join vessels called venules, then wider veins, and finally main veins, which take the low-oxygen blood back to the heart. Since this blood is at low pressure, the vein walls are thin, stretchy, and limp. Veins also have flap-shaped, one-way valves to ensure that the blood flows in only one direction.

“The body cannot feel constant speed – it only detects changes in speed”

Surviving high g-force
An F-16 jet pilot wears a g-suit with balloon-like chambers around the lower body. At high g-forces, these automatically inflate to press on the body and prevent blood from pooling in the lower legs.

FIGHTING G-FORCE

Maintaining flow

The heart and blood vessels usually adjust to cope with the effects of motion and the pull of Earth's gravity (g-force). This ensures blood reaches all parts of the body, especially the brain. But as the body speeds faster, brakes harder, or takes a sharp turn, unnaturally high forces disturb blood flow, which the heart cannot deal with. Blood then collects in the lowest parts of the body, starving the brain of oxygen and energy. This can result in a sudden loss of consciousness – a total blackout.

STATS AND FACTS

EFFECTS OF GRAVITY

Standing still, we are pulled towards Earth by the force of gravity (1 g). The faster you speed up or slow down while moving, the more g-force you feel.

3–4 g-force ROCKET LAUNCH

4–5 g-force ROLLER COASTER

9–12 g-force FAST JET TURN

BLOOD VOLUME

20% How much less blood an astronaut has in space compared with on Earth

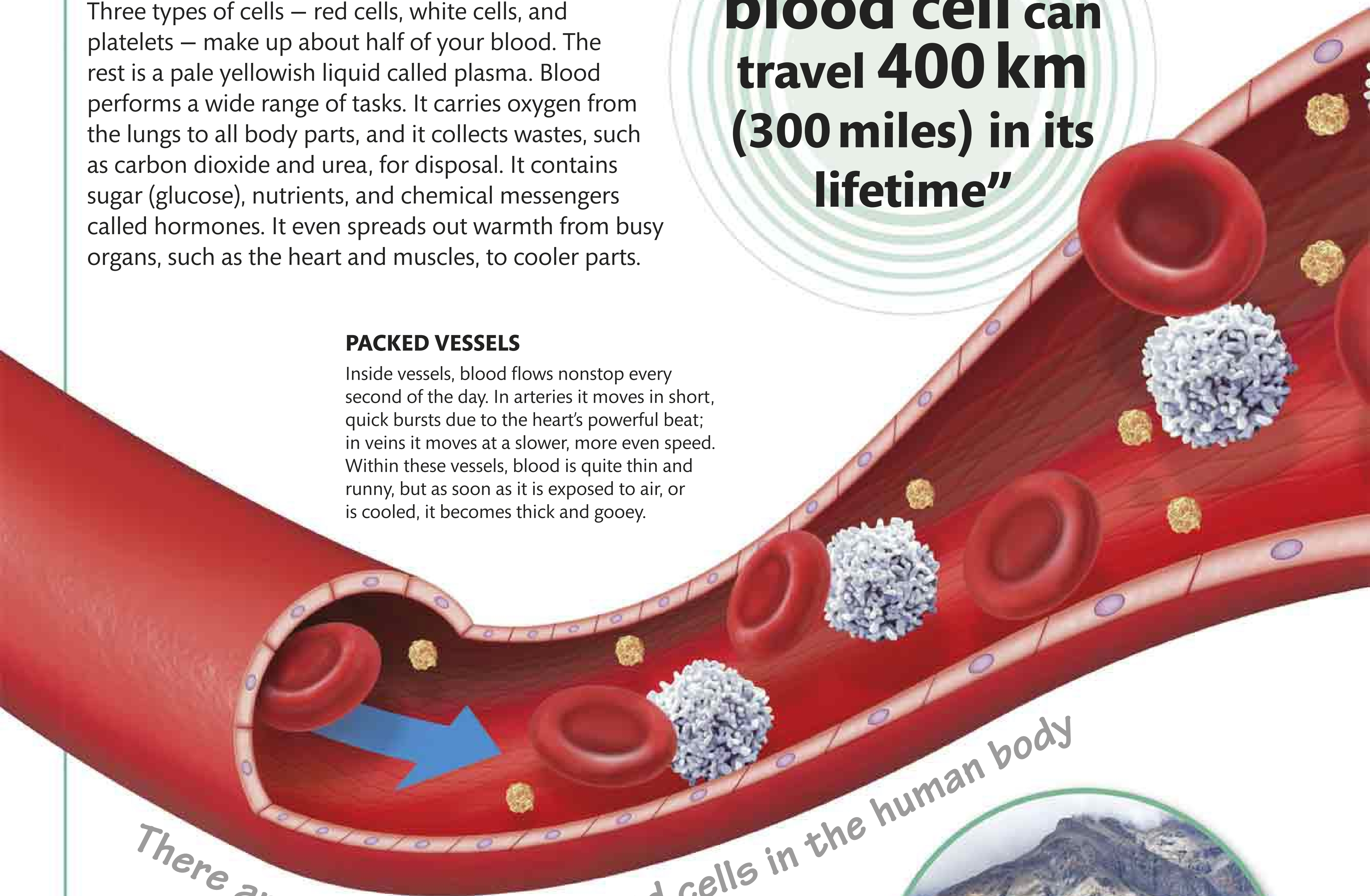
HUMAN G-FORCE LIMIT **46**

BLOOD SUPERHIGHWAY

What's in the blood

Blood is the vital fluid that keeps the body alive. Three types of cells – red cells, white cells, and platelets – make up about half of your blood. The rest is a pale yellowish liquid called plasma. Blood performs a wide range of tasks. It carries oxygen from the lungs to all body parts, and it collects wastes, such as carbon dioxide and urea, for disposal. It contains sugar (glucose), nutrients, and chemical messengers called hormones. It even spreads out warmth from busy organs, such as the heart and muscles, to cooler parts.

"A single red blood cell can travel 400 km (300 miles) in its lifetime"



PACKED VESSELS

Inside vessels, blood flows nonstop every second of the day. In arteries it moves in short, quick bursts due to the heart's powerful beat; in veins it moves at a slower, more even speed. Within these vessels, blood is quite thin and runny, but as soon as it is exposed to air, or is cooled, it becomes thick and gooey.

There are 25 trillion red blood cells in the human body

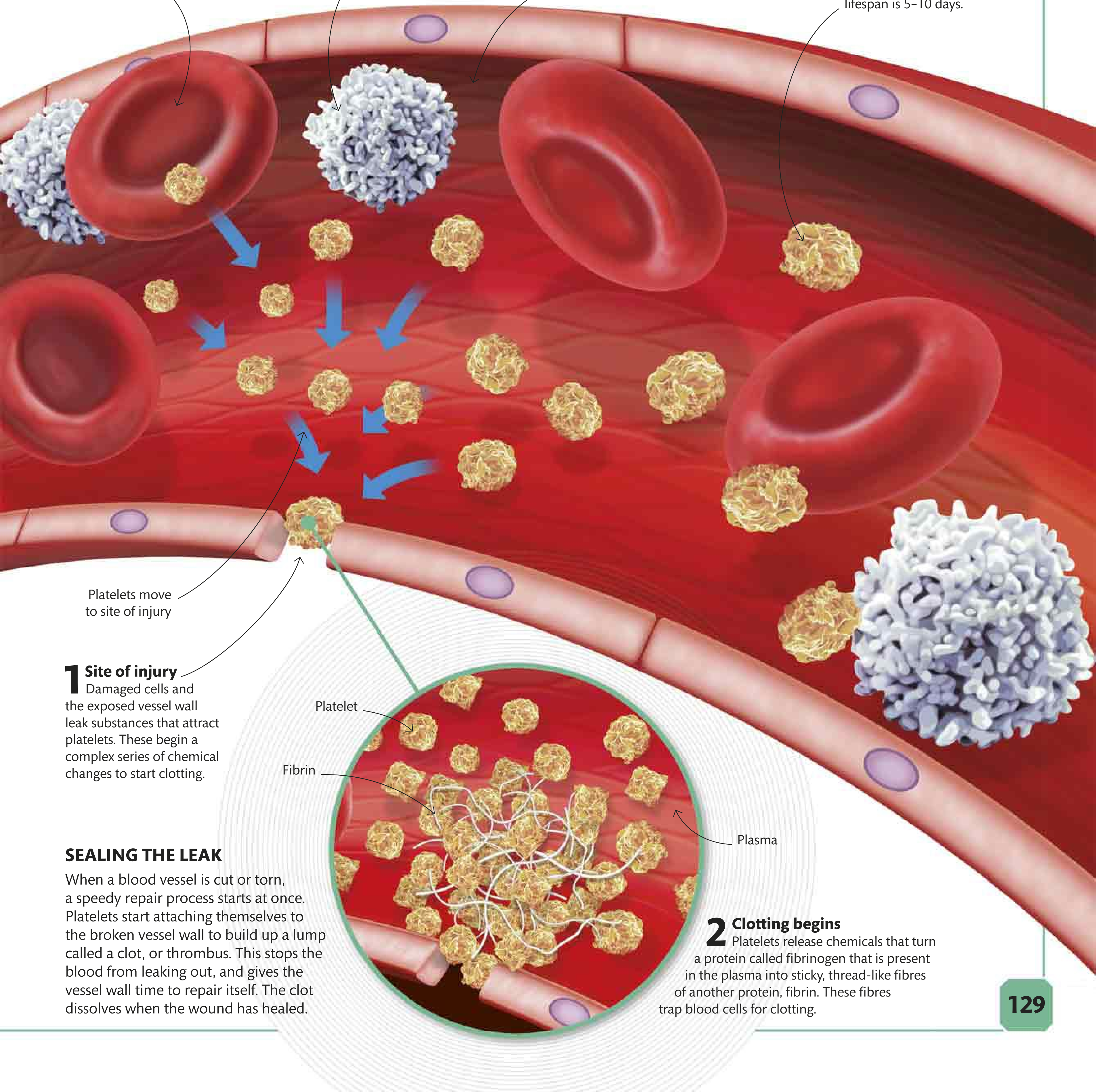
SOME BLOOD CELLS LIVE FOR A YEAR OR MORE

DIZZYING HEIGHTS

People living high in the mountains have more red blood cells containing more haemoglobin than people who live at lower levels. The chest, including the lungs and heart, is larger. More haemoglobin and a larger chest help people to get as much oxygen from the air as possible.

SEALING THE LEAK

When a blood vessel is cut or torn, a speedy repair process starts at once. Platelets start attaching themselves to the broken vessel wall to build up a lump called a clot, or thrombus. This stops the blood from leaking out, and gives the vessel wall time to repair itself. The clot dissolves when the wound has healed.



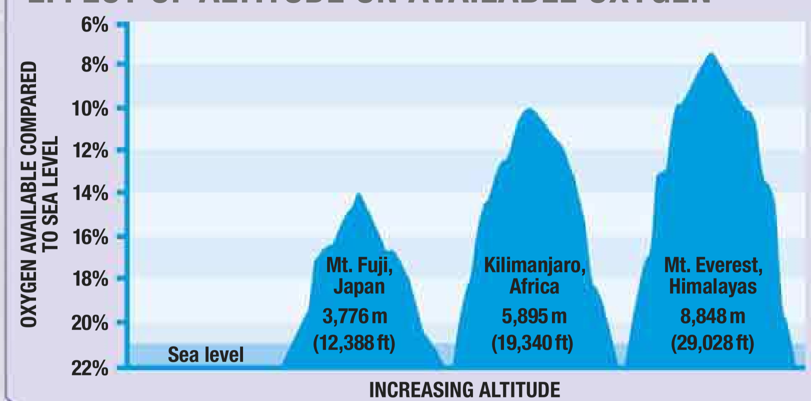
CLIMBING HIGH

Oxygen levels

Higher air is thinner air – and the lack of oxygen and lower air pressure can leave you gasping for breath. At 3,000 m (9,900 ft), there is just two-thirds of the oxygen at sea level, yet the respiratory system still copes. But even at this height, one person in five develops altitude sickness, and above 4,000 m (13,000 ft), one in two. It is best to climb up by around 500 m (1,600 ft) a day, which allows the body to gradually increase its red cells so that it can pick up more of the scarce oxygen.

STATS AND FACTS

EFFECT OF ALTITUDE ON AVAILABLE OXYGEN



"Your nose clogs more frequently at altitude, adding to the pressure on your lungs"

Hitting the wall
Heavy backpack adding to the body's load, the panting climber chips cautiously up an almost sheer wall of ice. Several days of getting used to the thin air has lessened the risk of feeling dizzy – or even blackout.

RED ARMY

Blood cells

The number of red blood cells in the body is astonishing – they make up about one-quarter of the total. As they journey around the body, the red pigment they contain, haemoglobin, takes up oxygen from the lungs, and then releases it when the cells reach the tissues. They also carry some waste carbon dioxide from the tissues back to the lungs, although about three-quarters of the carbon dioxide is dissolved in the liquid part of the blood, called plasma.

STATS AND FACTS

RED BLOOD CELL TRAVEL TIME

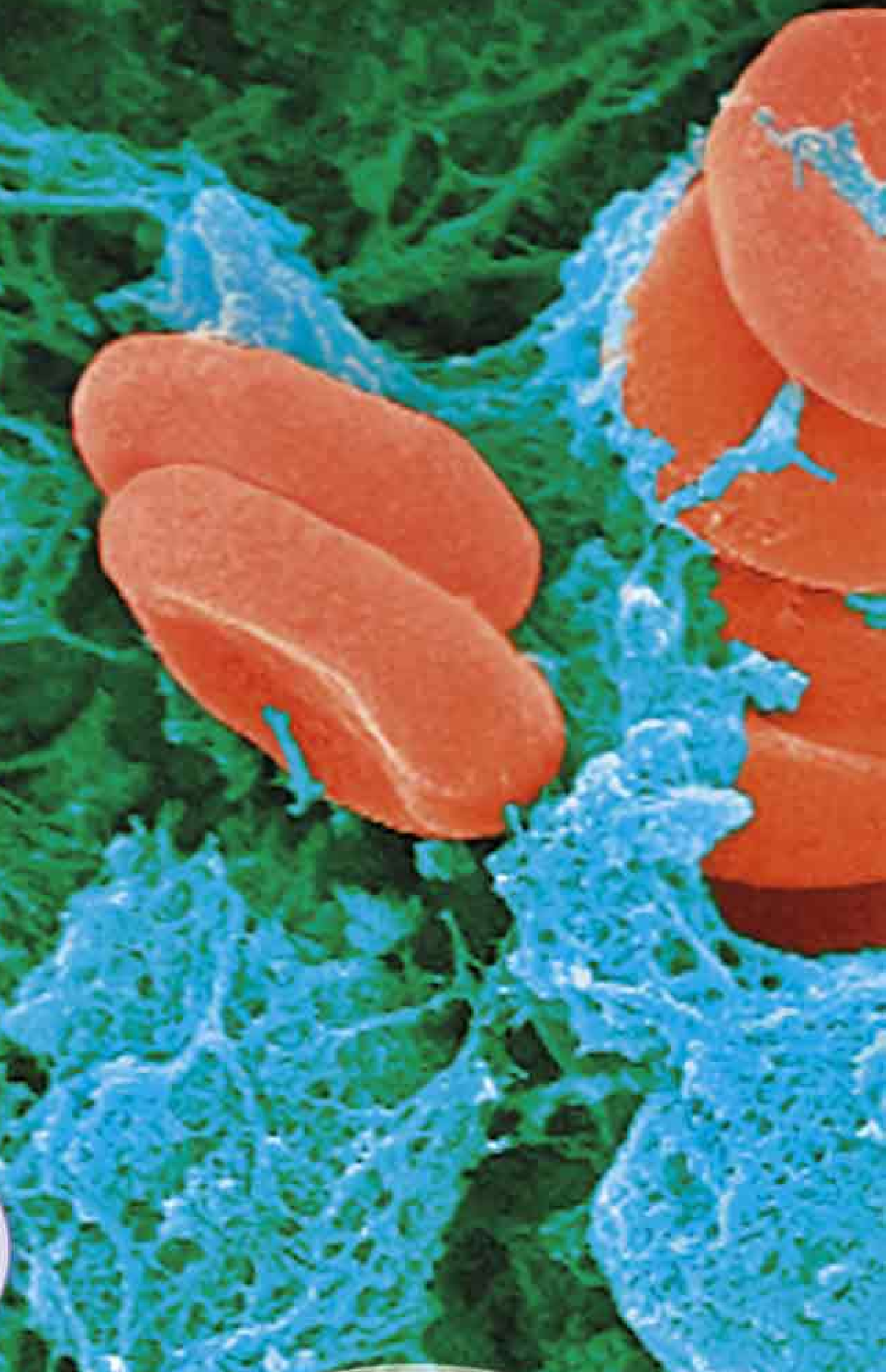
5 SECONDS
Through the chambers of the heart

30 SECONDS
From the heart to the toes and back

CELL SIZE

A line of
1,500
red blood cells would cover a distance of 1 cm (⅖ in)

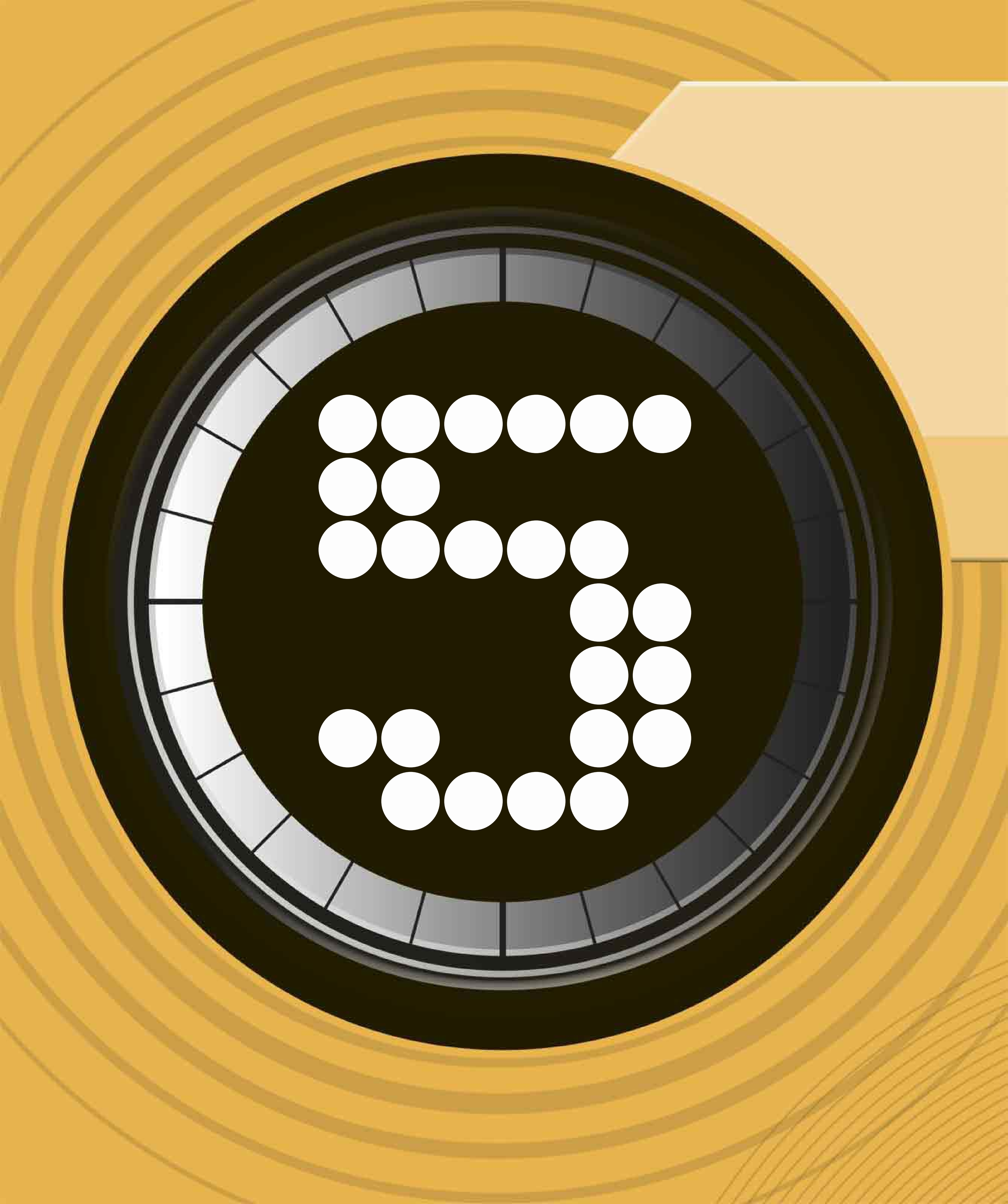
LIFESPAN OF A RED BLOOD CELL
3–4 MONTHS



"We make 2.4 million red cells each second of every day"

In a tangle

As red cells travel in the bloodstream, they may get stuck in thread-like clumps of the substance fibrin. This is produced after damage to the vessel wall, and will build up a sticky lump called a blood clot.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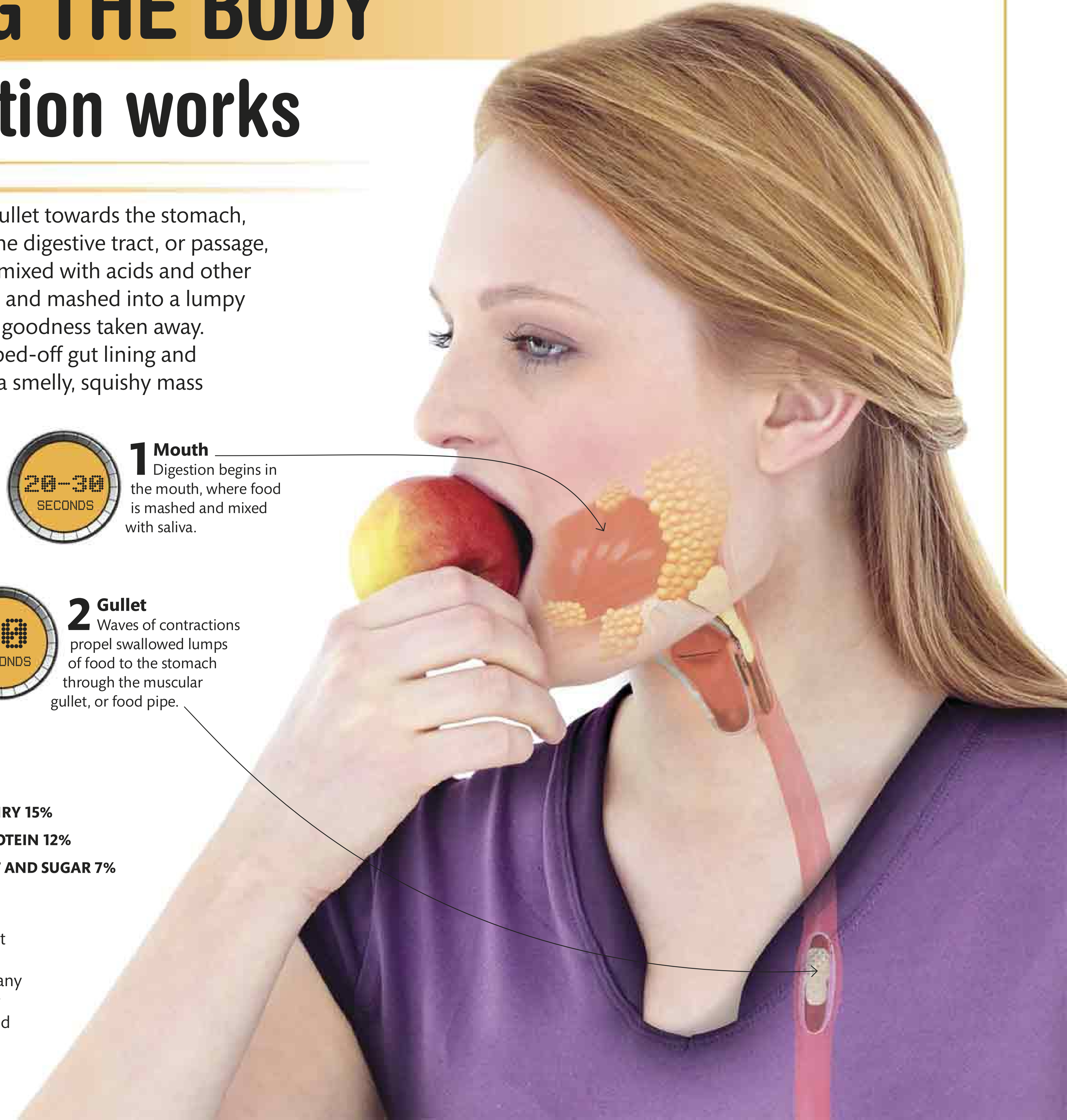
FUEL AND WASTE

Super machines need fuel, care, adjustments, and regular removal of unwanted garbage. The digestive and excretory systems do these jobs every hour of every day, allowing the rest of the body to perform at its maximum.

FUELLING THE BODY

How digestion works

As chewed food slips down the gullet towards the stomach, it begins an epic journey through the digestive tract, or passage, lasting 24 hours or more. It will be mixed with acids and other powerful digestive juices, squeezed and mashed into a lumpy soup, and have all its nutrients and goodness taken away. Then the leftovers, mixed with rubbed-off gut lining and billions of dead bacteria, will form a smelly, squishy mass that's ready for removal.



1 Mouth Digestion begins in the mouth, where food is mashed and mixed with saliva.

2 Gullet Waves of contractions propel swallowed lumps of food to the stomach through the muscular gullet, or food pipe.

KEY

- FRUIT AND VEGETABLES 33%
- CARBOHYDRATES 33%
- DAIRY 15%
- PROTEIN 12%
- FAT AND SUGAR 7%

BALANCED DIET

To stay healthy, we need to eat a balanced diet of different types of foods, ideally in the same proportions as the chart above. Too much of any single food can affect digestion and necessary supplies of energy, body-building proteins, and substances such as minerals and salts.

YOUR GUT MEASURES AROUND 9 M (30 FT) FROM MOUTH TO ANUS

YOU ARE WHAT YOU EAT

Maintaining a healthy body requires a regular input of key nutrients. Most food items contain a mix of these nutrients – for example, brown bread has carbohydrates, vitamins, minerals, and fibres.

Proteins

These are broken down into simpler units called amino acids, which are then built up into structural materials, such as bones, cartilage, muscles, and skin.

Carbohydrates

These are taken apart to make smaller subunits – sugars such as glucose – that are the main source of energy for all body cells and tissues.

Fats

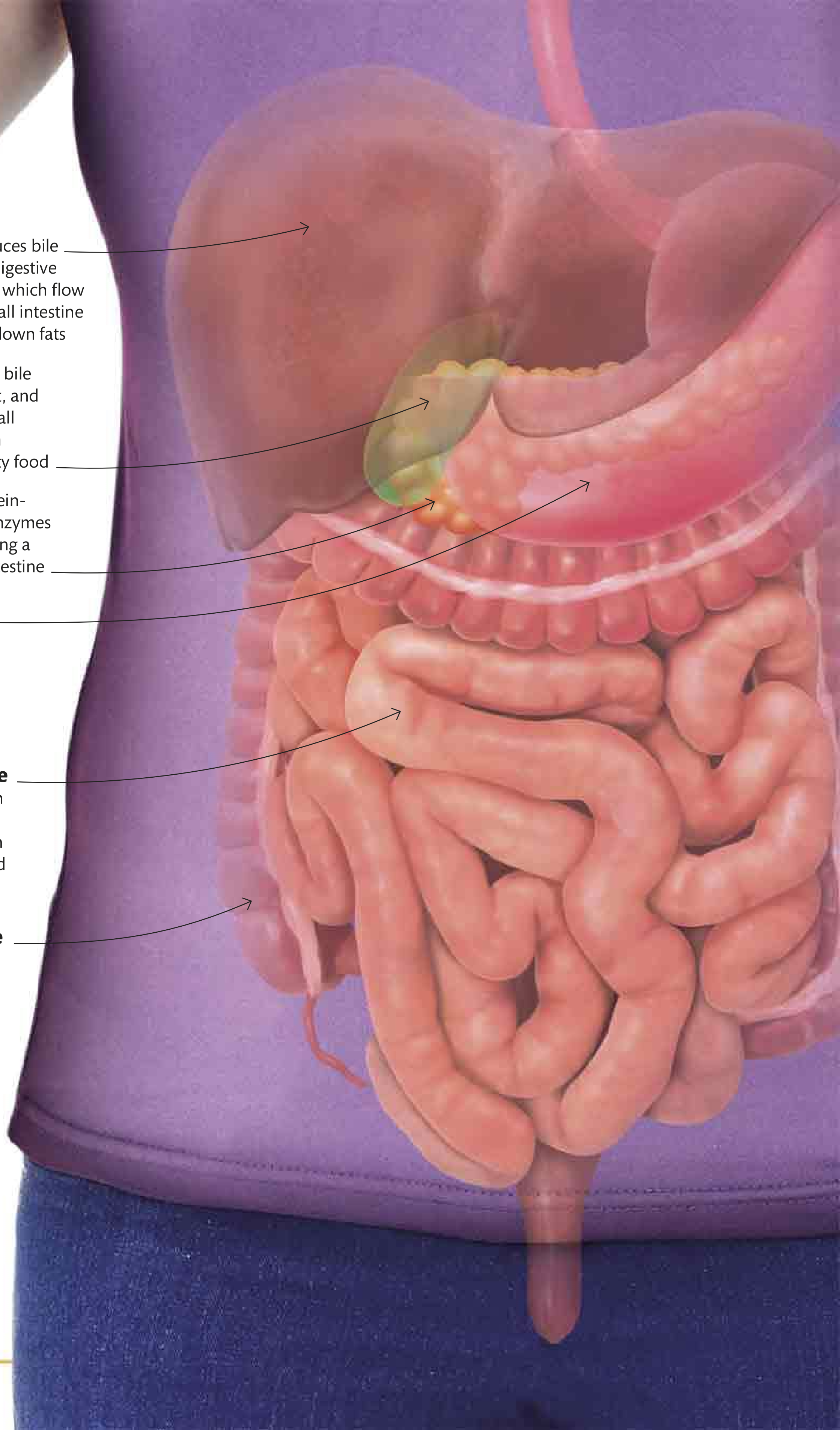
Fats are essential for various parts of the body, such as cell membranes and the protective covering of nerve fibres. They also supply energy to the body.

Vitamins and minerals

More than 30 vitamins and minerals, including calcium and sodium, are vital for the smooth running of the body's chemical processes.

Fibre

Present in fruits and vegetables, fibre provides bulk for food and helps it move along the gut. It also helps in digestion and the absorption of other nutrients.



Liver produces bile and other digestive substances, which flow into the small intestine and break down fats

Gall bladder receives bile from the liver, stores it, and releases it into the small intestine, as and when required, to digest fatty food

Pancreas makes protein-digesting and other enzymes and releases them along a tube into the small intestine

2–4 HOURS

3 Stomach Churns to mash food further, and adds strong acids and digestive enzymes.

4–6 HOURS

4 Small intestine Breaks food down into a liquid and lets nutrients pass through its lining into the blood and lymph.

12–16 HOURS

5 Large intestine and rectum Absorb minerals and water from digested food, which then becomes faeces.

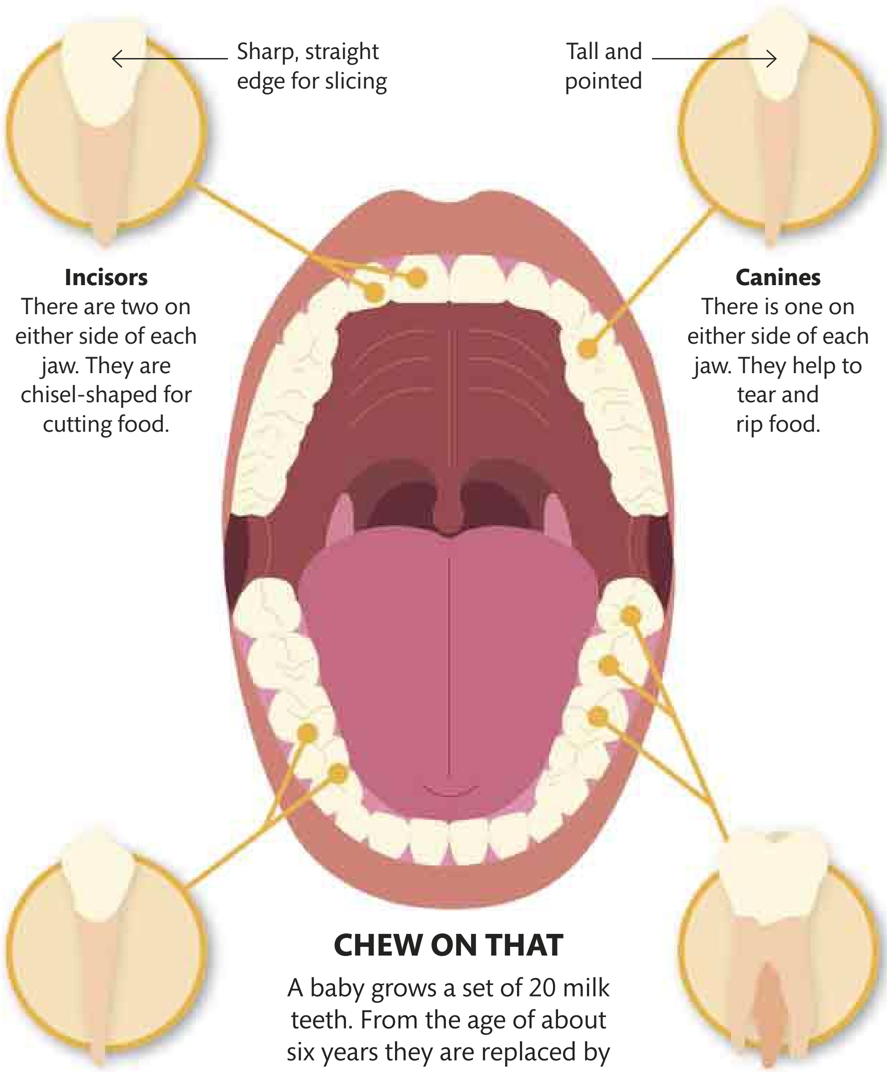
DIGESTION IN ACTION

The long passageway for food, from mouth to anus, is known as the gut, or digestive tract. Two organs that are not part of the tract, but make essential products for digestion, are the liver and pancreas.

DOWN THE HATCH

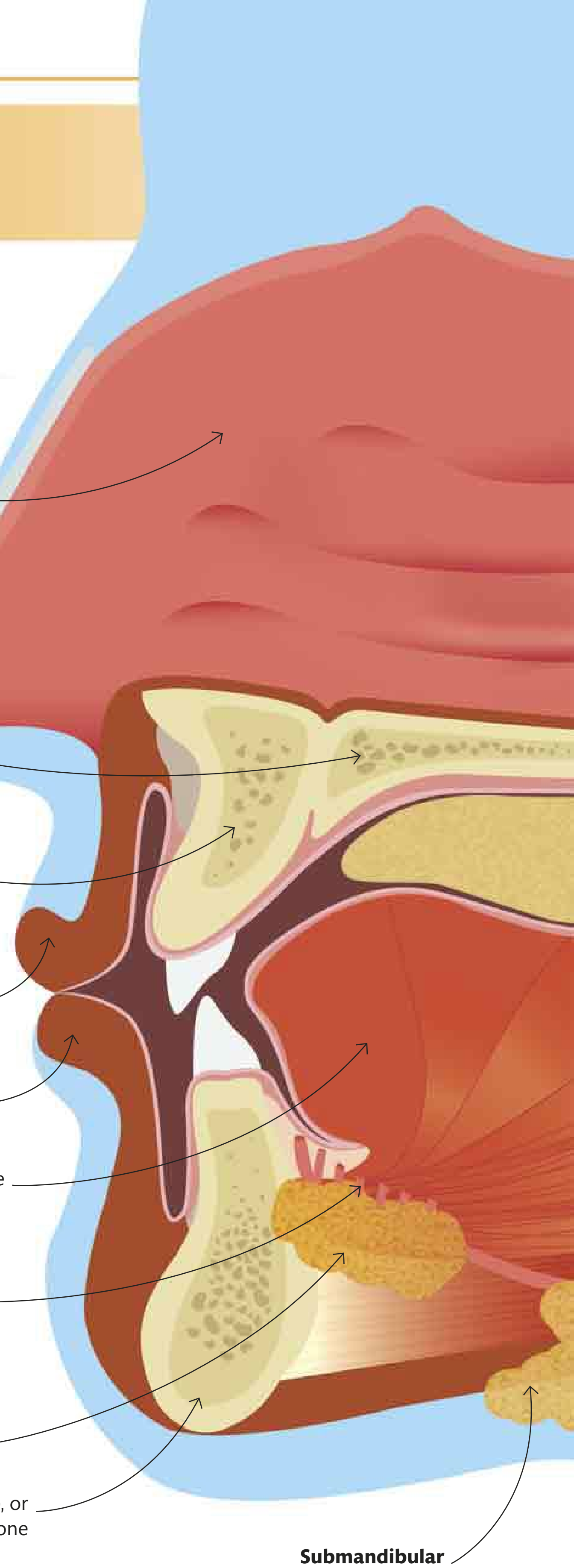
Chew and swallow

The body wastes no time when it comes to digestion. It starts at the first bite. The teeth chop and chew food to a squishy mass, while mixing it with saliva, or spit, which contains digestive substances called enzymes. The tongue keeps the food moving around until it is fully mashed. All this pulps the food into soft lumps that are easy to swallow, ready for the stomach to continue the digestion.



CHEW ON THAT

A baby grows a set of 20 milk teeth. From the age of about six years they are replaced by 32 adult, or permanent, teeth. These have different shapes for specialized tasks, and their whitish covering – enamel – is the hardest substance in the entire human body.



THE INSIDE STORY

As three pairs of salivary glands pour out their watery saliva along tubes or ducts, the tongue shifts food to the type of teeth most suited to each stage of chewing. It also presses the chewed chunks against the hard palate, pushing the food backwards down the throat.

STATS AND FACTS

SALIVA FACTS

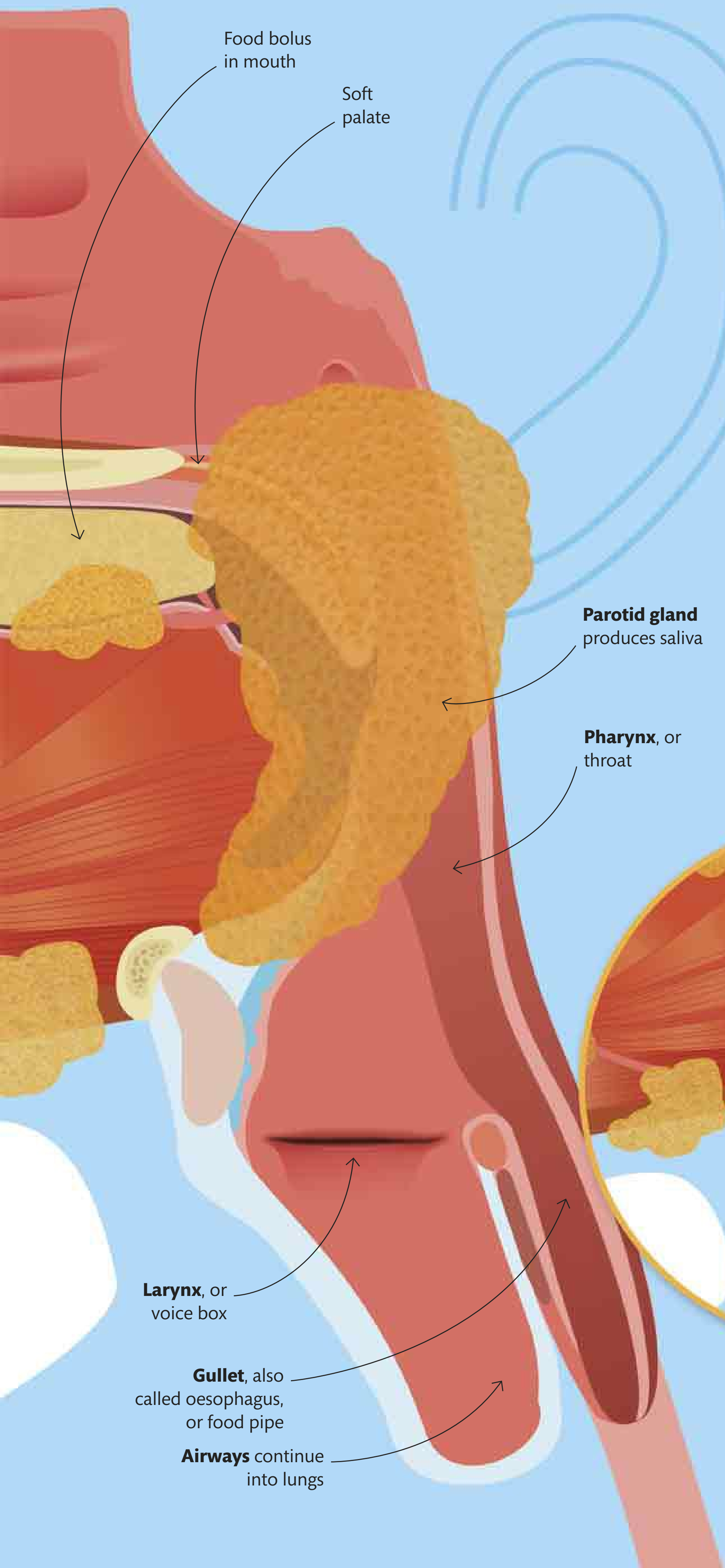
1 LITRE (2 pints) The amount of saliva the mouth produces in a day

99.5% The amount of water in saliva. The rest is mucus, enzymes, and bacteria.

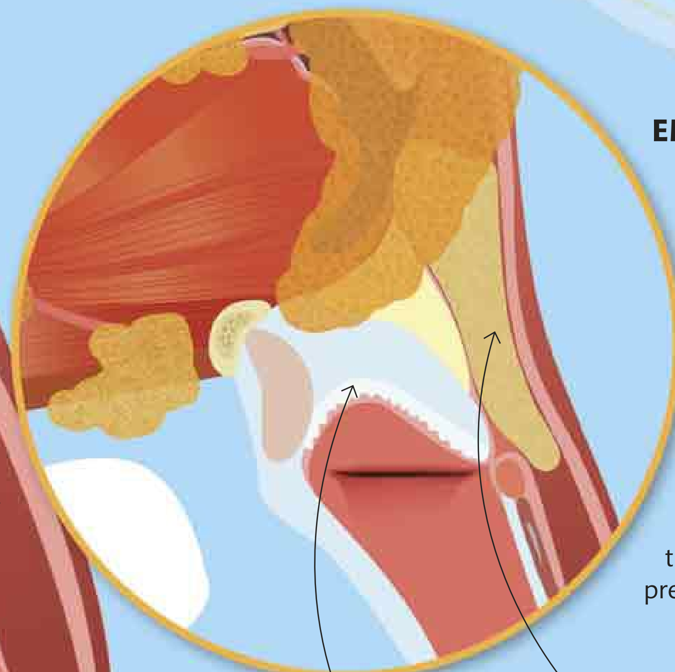
BITE FORCE

CROCODILE **1,134 kg** (2,500 lb)

HUMAN **55 kg** (120 lb)



"You don't need gravity to swallow – astronauts can eat upside down in space"



EMERGENCY STOPPER

The tongue squeezes food into lumps and pushes each to the back of the mouth. The throat muscles close around them and shove them into the gullet, by the process of peristalsis. As each lump slides down, it bends a flap of cartilage, called the epiglottis, closing off the windpipe to prevent choking.

ACID BATH

Inside the stomach

An empty stomach is smaller than a clenched fist, folded and shrivelled, while a full one – stretched tight like a balloon – can be almost football-sized! This organ works as a store so we can eat a big meal within a few minutes, then digest it over several hours. It also continues the physical and chemical breakdown of food that began in the mouth. The stomach's powerful wall muscles churn and crush its contents, while its lining pours out powerful acids, enzymes, and other digestive juices.

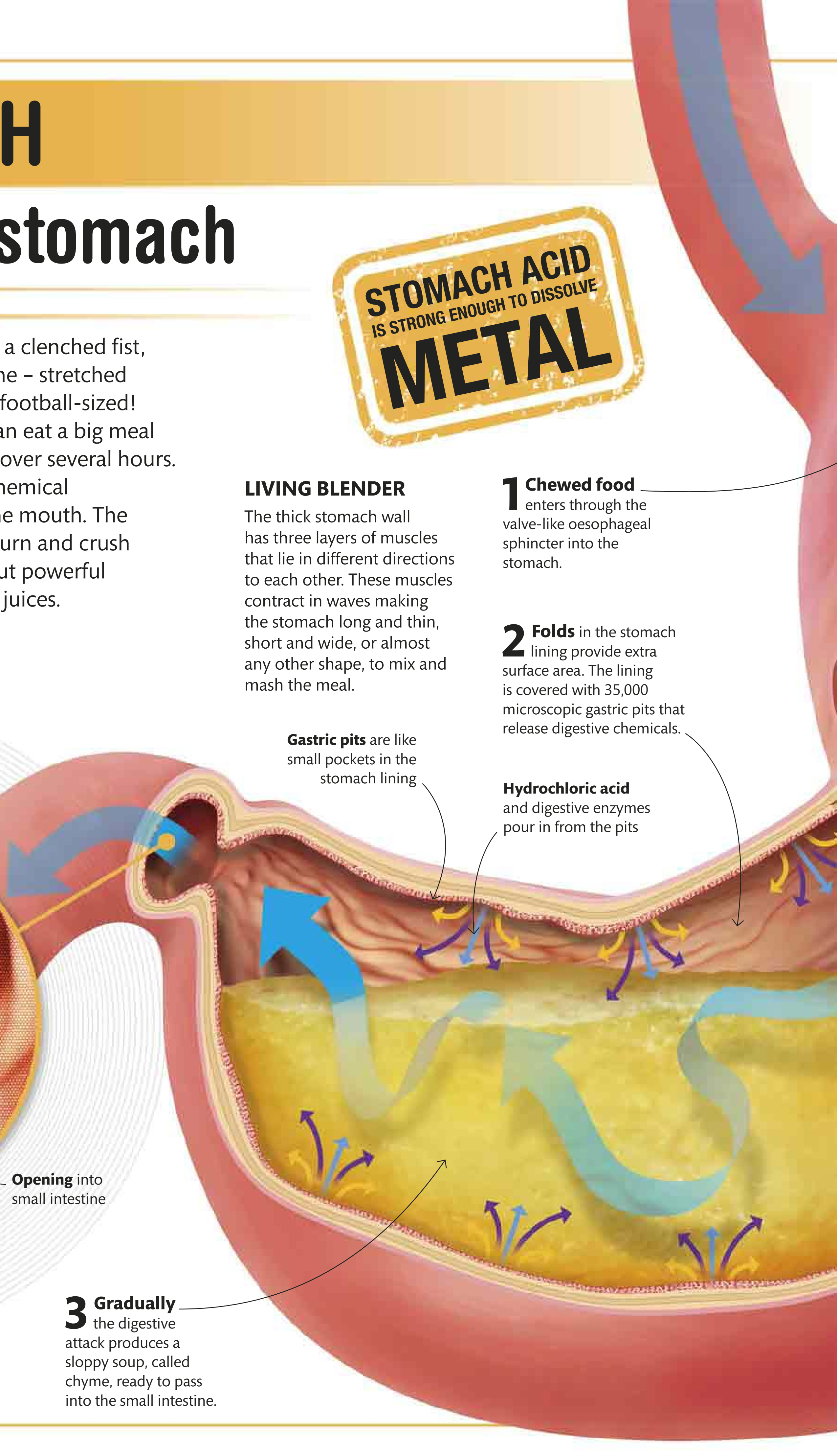
STOMACH ACID IS STRONG ENOUGH TO DISSOLVE METAL

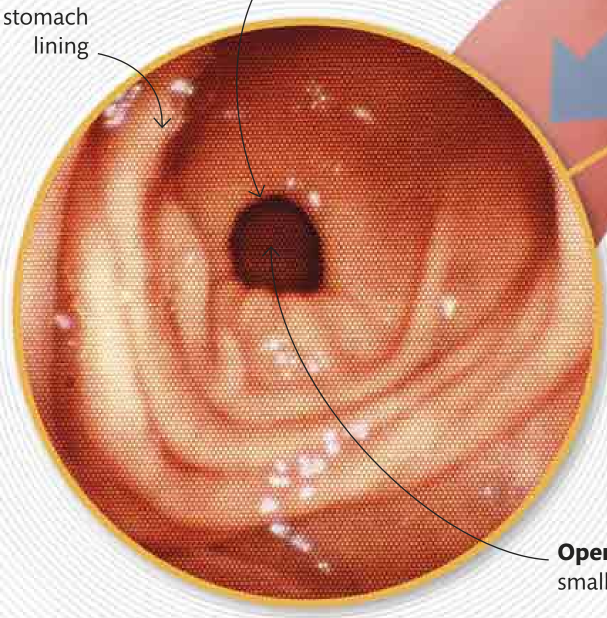
LIVING BLENDER

The thick stomach wall has three layers of muscles that lie in different directions to each other. These muscles contract in waves making the stomach long and thin, short and wide, or almost any other shape, to mix and mash the meal.

1 Chewed food enters through the valve-like oesophageal sphincter into the stomach.

2 Folds in the stomach lining provide extra surface area. The lining is covered with 35,000 microscopic gastric pits that release digestive chemicals.





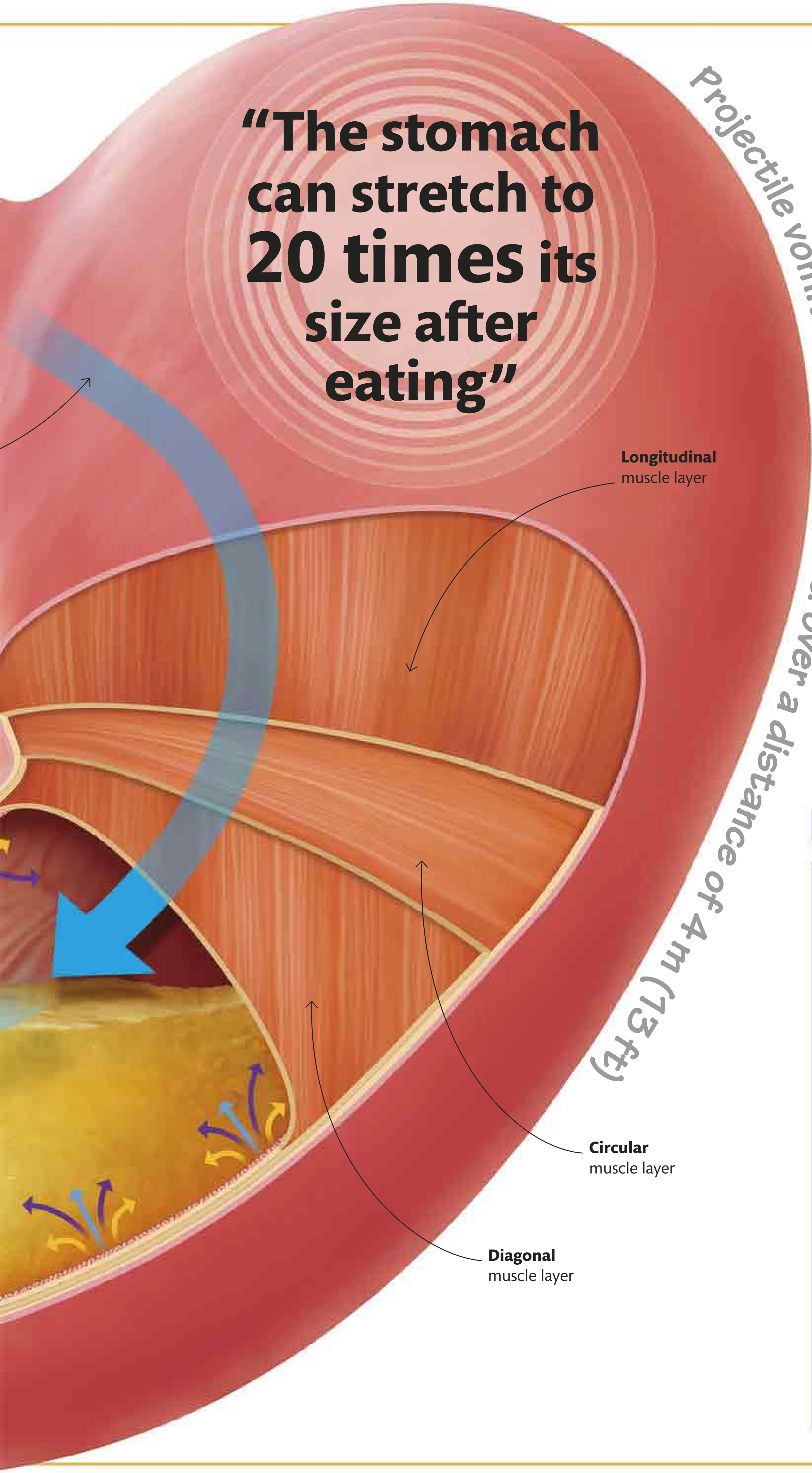
THE GATEKEEPERS

At both ends of the the stomach are tight rings of muscles called sphincters. These keep the food and digestive juices in the stomach while it is being churned and regulate how much food enters and leaves the stomach.

3 Gradually the digestive attack produces a sloppy soup, called chyme, ready to pass into the small intestine.

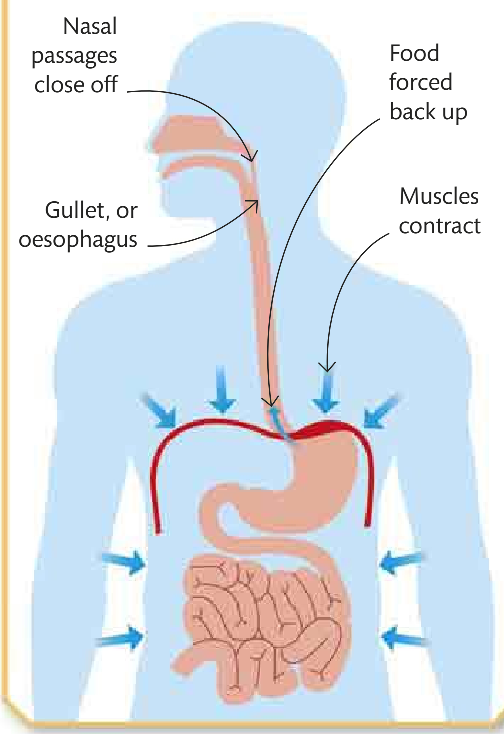
"The stomach can stretch to 20 times its size after eating"

Projectile vomiting can hurl food over a distance of 4 m (13 ft)



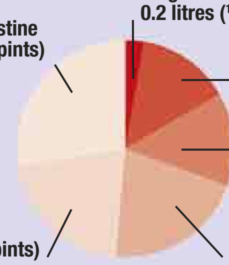
UP IT COMES

Rotting or poisonous food irritates the stomach lining, which sends nerve signals to the brain to trigger vomiting. The stomach, the diaphragm above it, and abdomen muscles around it, all contract to push the food back into the gullet and force it out through the mouth.



STATS AND FACTS

DAILY PRODUCTION OF DIGESTIVE FLUIDS



95% of water in the digestive system is recycled

STOMACH VOLUME

Normal **0.5** LITRES (1 pint)

Maximum size **10** LITRES (21 pints)

ULTIMATE ACID PIT

Inside the stomach

Every time food enters our stomach, tiny gastric pits in the lining ooze out acid and enzymes to break it down. But if these digestive juices are so powerful, why does the stomach not digest itself? First, the enzymes are not active when they're made – they only become active when they mix with the acidified food. Second, the lining also produces a thick layer of mucus that stops the juices from attacking it. The mucus also makes the food more squishy and slippery so it moves through the stomach easily.

STATS AND FACTS

MEASURING ACID STRENGTH (pH)

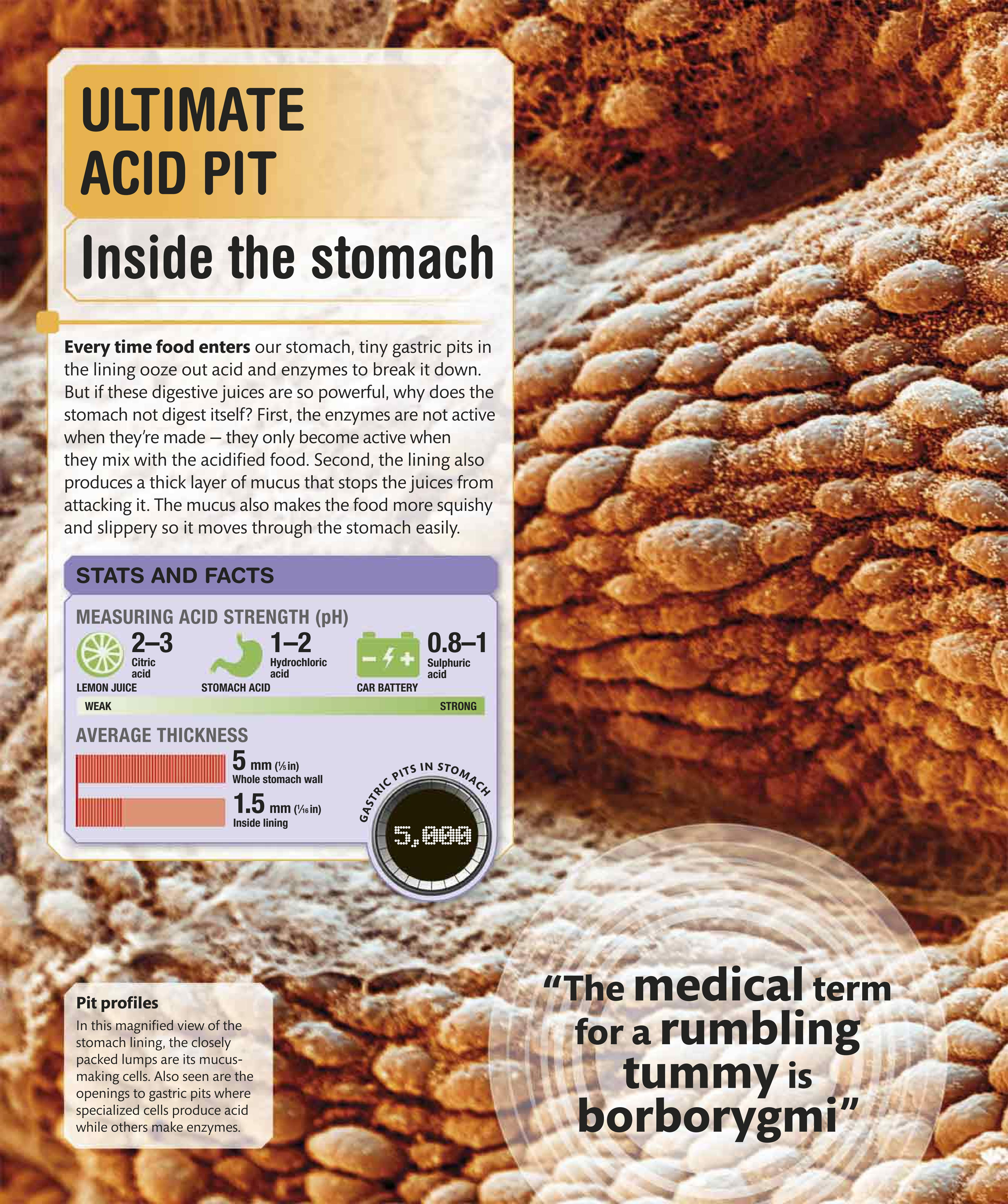
LEMON JUICE	STOMACH ACID	CAR BATTERY
2–3	1–2	0.8–1
Citric acid	Hydrochloric acid	Sulphuric acid

WEAK → STRONG

AVERAGE THICKNESS

- **5** mm (1/5 in) Whole stomach wall
- **1.5** mm (1/16 in) Inside lining

GASTRIC PITS IN STOMACH: 5,000



Pit profiles

In this magnified view of the stomach lining, the closely packed lumps are its mucus-making cells. Also seen are the openings to gastric pits where specialized cells produce acid while others make enzymes.

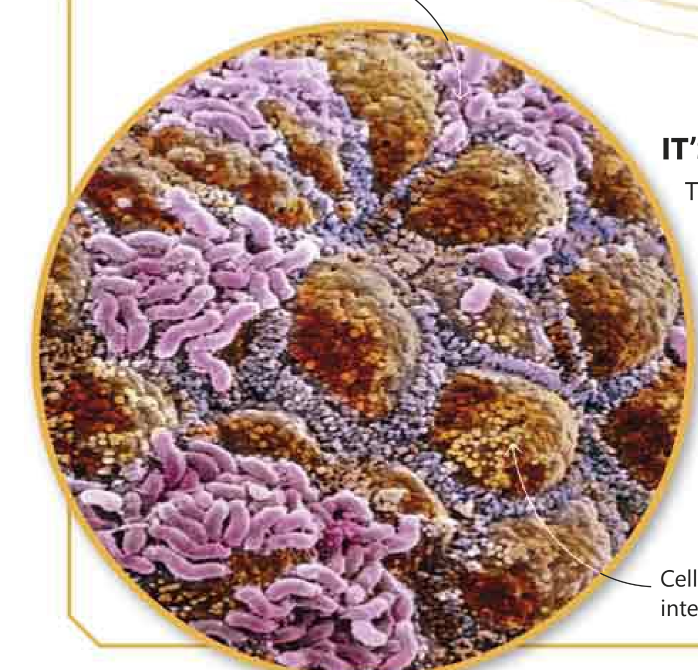
> "The **medical** term for a **rumbling tummy** is **borborygmi**"

GUT REACTIONS

Inside the intestines

A few hours after a meal, globs of smelly, soupy, and part-digested food (called chyme) spurt from the stomach into the intestines every few minutes. First to deal with the chyme is the slim but very long small intestine, which breaks it down further to extract the nutrients. These pass through the lining of the intestine into the millions of blood capillaries within its wall, which carry the blood to the liver. The undigested leftovers move on to the shorter, wider large intestine, where water and a few other substances are removed before the rest travels on to leave the body.

"Your guts produce around a litre (2 pints) of gas every day"

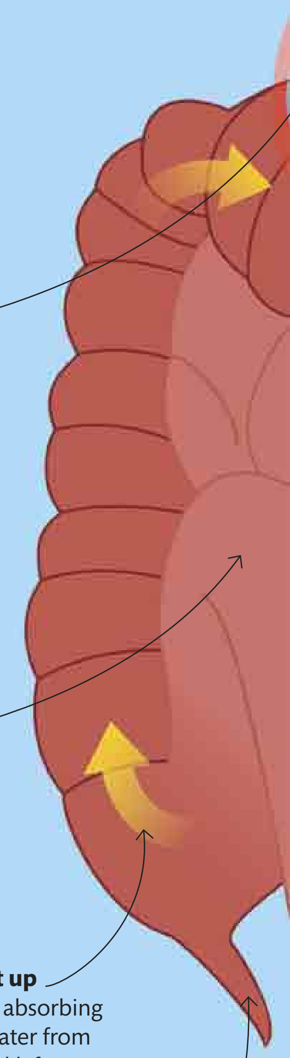


IT'S A GAS!

The large intestine is home to at least 5,000 different types of bacteria, and there are 10 times more bacterial cells there than cells in the rest of the body. They help with the last stages of digestion and with absorbing essential minerals and salts. But they also make gases such as methane, which must come out sometime.

TWISTS AND TURNS

The small intestine is more than 6 m (20 ft) long but only 3 cm (1¼ in) wide and has many bends, folds, and coils. It leads into the first part of the large intestine, called the caecum, which connects to the colon. The large intestine loops around the small intestine and is 1.5 m (5 ft) long (about the length of a bicycle) and 7 cm (2 ¾ in) wide.



1 Little squirts
As food moves out of the stomach, digestive juices from the pancreas gland and the liver are squirted into the duodenum, the first section of the small intestine. These juices help break down fats and proteins.

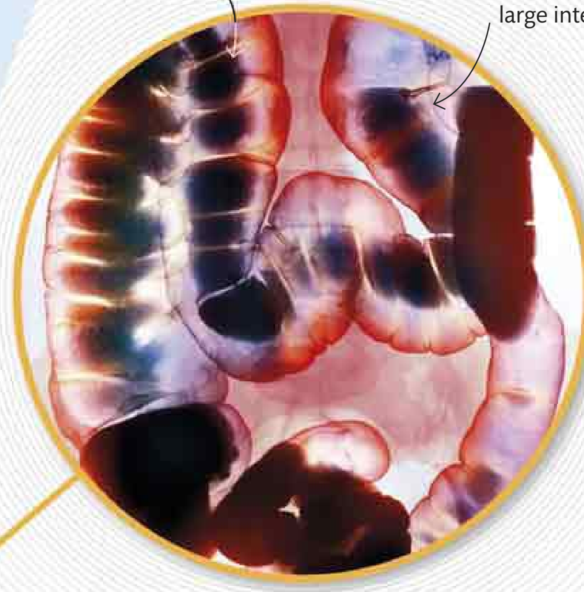
2 Sticky fingers
The lining of the small intestine is covered with millions of tiny, finger-like projections called villi. The villi increase the surface area of the gut, helping nutrients to be absorbed more rapidly.

3 Soaking it up
As well as absorbing most of the water from the undigested leftovers through its lining, the large intestine absorbs body salts and minerals such as sodium.

The appendix keeps a supply of bacteria in case a digestive problem wipes them out in the main part of the gut

THERE ARE ABOUT 5 MILLION VILLI IN THE SMALL INTESTINE

4 Final exit The semi-solid leftovers, called faeces, are stored in the lower colon and the final part of the large intestine, the rectum. From there, they pass out through the anus.

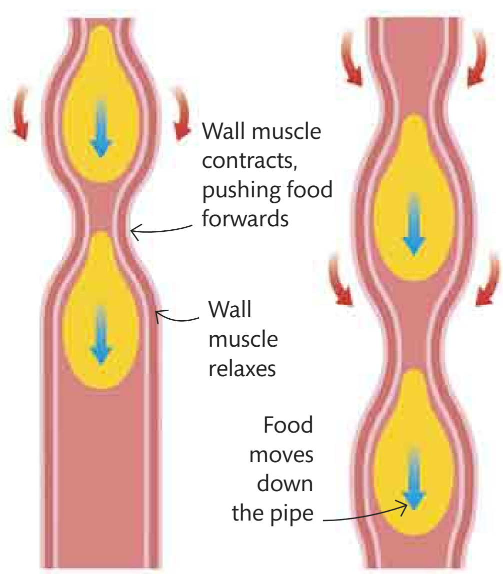


END OF THE LINE

When the food has been broken down, what is left is a mixture of insoluble fibre and dead bacteria. This forms pellets inside the large intestine. Water and minerals are drawn out of the pellets as they pass along the colon. The pellets collect in the rectum before being expelled through the anus.

PERISTALSIS

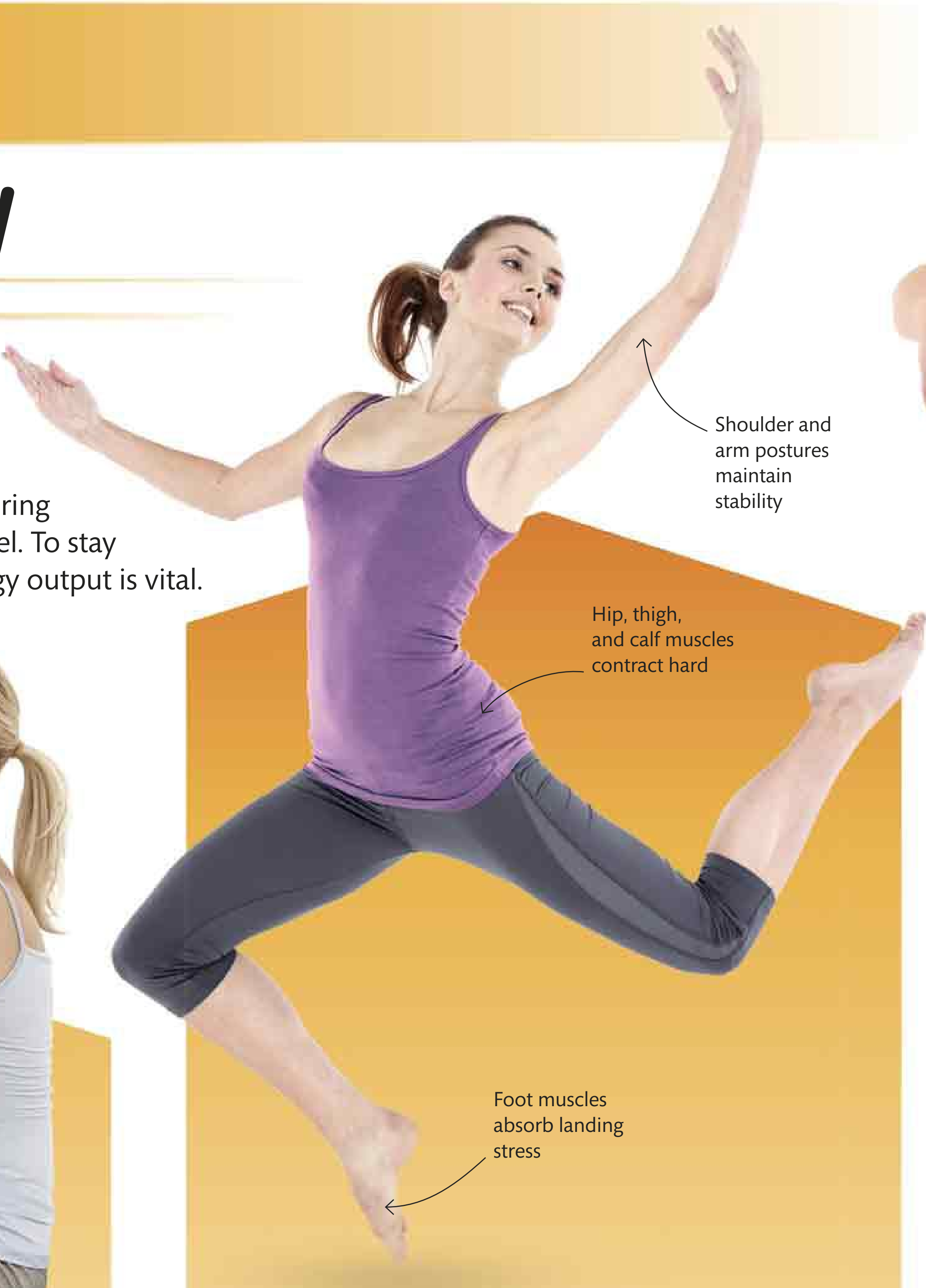
Food does not simply fall down the passages of the gullet, stomach, and intestines. These organs are packed into the body and are under pressure from all sides. So, at every stage their contents are pushed along by a powerful, wave-like motion called peristalsis. This is created by muscles in the passage walls, which contract with a squeezing action that pushes the food ahead.



FUEL UP!

Food as energy

You are a powerhouse of energy use. At maximum output, such as when sprinting, the body consumes more than 20 kcal (Calories) of energy per minute. Over a 12-hour day this would need the energy in 50 chocolate bars! During normal daily activities the body needs far less fuel. To stay healthy a balance between food input and energy output is vital.



LEVELS OF ACTIVITY

All body parts use energy all the time simply to stay alive. Even during sleep the heart beats and the lungs breathe. As soon as the muscles start working, energy needs rise rapidly.

LOW LEVEL

Lying flat requires the least energy since most muscles can relax, and so they only need energy for their minimal life processes. Compared to lying down, standing still in a relaxed way increases energy use by two times, and slow walking by around three times.

- **SITTING** Leg and arm muscles mostly relax, torso and neck keep balance
- **STANDING** Leg, torso, and neck muscles continually shift to maintain balance
- **SLOW WALKING** Leaning forwards slightly gives momentum to save some energy

ENERGY USED PER MINUTE
2–5
KCAL

MEDIUM LEVEL

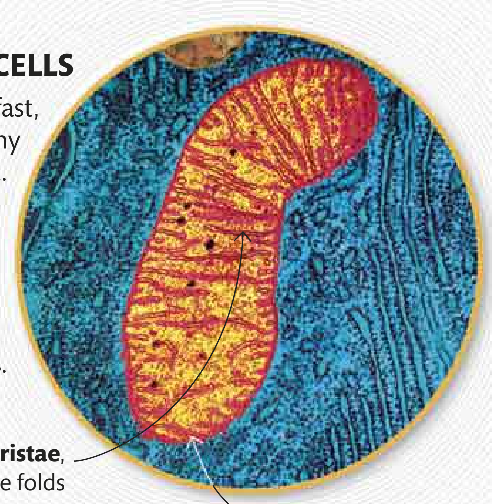
As more muscles start working, they demand more oxygen and energy in the form of glucose, or sugar. This increases heartbeat and breathing rates – also muscle-powered – so push up energy needs even more. Leg muscles are the biggest and so use the most energy.

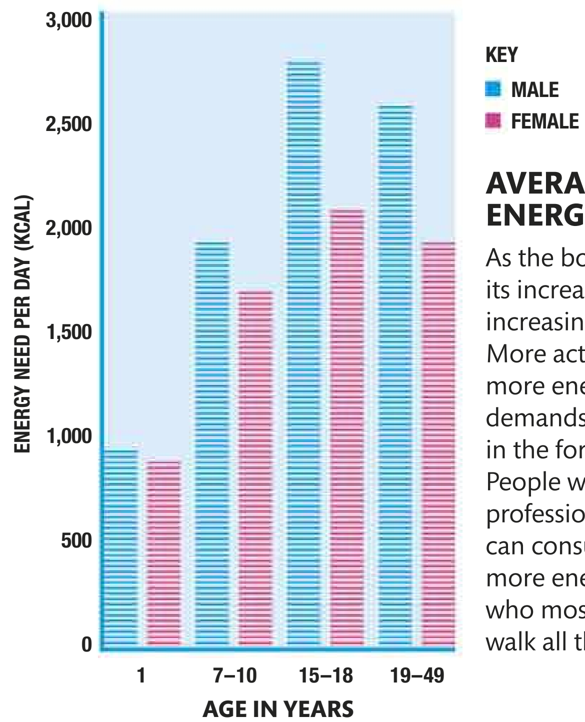
- **CYCLING** The energy-efficient bicycle reduces energy needs greatly compared to running
- **SLOW RUNNING** Arms swing more to maintain momentum and so add to energy needs
- **JUMPING** Large, powerful leg muscles greatly increase energy costs

ENERGY USED PER MINUTE
15–20
KCAL

FUEL CELLS

Cells that use energy fast, such as muscle cells, have many tiny parts called mitochondria. These contain special DNA that regulates energy in the cell. Here glucose is broken up to make high-energy molecules called ATP that fuel the cell's activities.





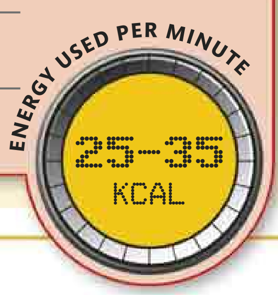
AVERAGE ENERGY NEEDS

As the body grows, its increasing bulk means increasing energy needs. More action also means more energy use, which demands more fuel energy in the form of foods. People with very active professions and lifestyles can consume three times more energy than people who mostly sit, stand, or walk all through the day.

MAXIMUM LEVEL

During strenuous activity almost every muscle works hard to move the body and its parts, to maintain posture and balance. Up to one-fifth of the energy used by some muscles is for contracting against other muscles, to ensure smooth coordination and prevent jerks.

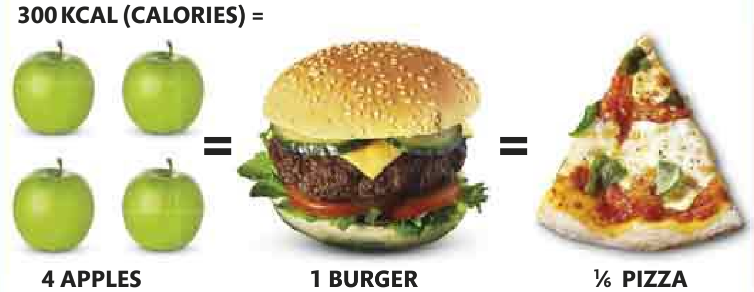
- **FAST RUNNING** As with walking, faster running means the arms work harder too
- **SWIMMING** Water resistance rises greatly with speed, demanding ever more muscle effort
- **SOCCER, SIMILAR SPORTS** Continual changes of speed and direction are very energy-hungry



ENERGY IN FOODS

Foods rich in sugars and other carbohydrates, proteins, and fats have the most energy. They include meat, fish, cheese, milk, and grain products. Weight for weight, fatty foods are the most efficient source of energy: 1 g of fat has 9 kcal (Calories) while 1 g of carbohydrate has 4 kcal (Calories). Some fat stays in the body as a vital store of energy. Vegetables and fruits contain less energy, but provide essential vitamins, minerals, and fibre.

300 KCAL (CALORIES) =



PUMPING UP THE POWER

Eating for energy

Extreme endurance is a severe test of your physical condition – including digestion, to fuel the body, and conserving water and fluids. Before endurance events, athletes "carb load", eating plenty of high-carbohydrate or starchy foods, such as pasta, bread, potatoes, and rice. These provide high-energy sugars, which are converted to glycogen (body starch) in the liver and the muscles. These energy stores can gradually be converted back to sugars during the long haul.

STATS AND FACTS

ENERGY USED

CYCLING
15 kcal/km
(24 Calories/mile)

WALKING
50–60 kcal/km
(80–97 Calories/mile)

RUNNING
60–80 kcal/km
(97–129 Calories/mile)

SWIMMING
120–150 kcal/km
(193–241 Calories/mile)

DAILY ENERGY

MAN
2,500
kcal (Calories)

ULTRA-ATHLETE
4,700
kcal (Calories)

POLAR EXPLORER
7,000+
kcal (Calories)

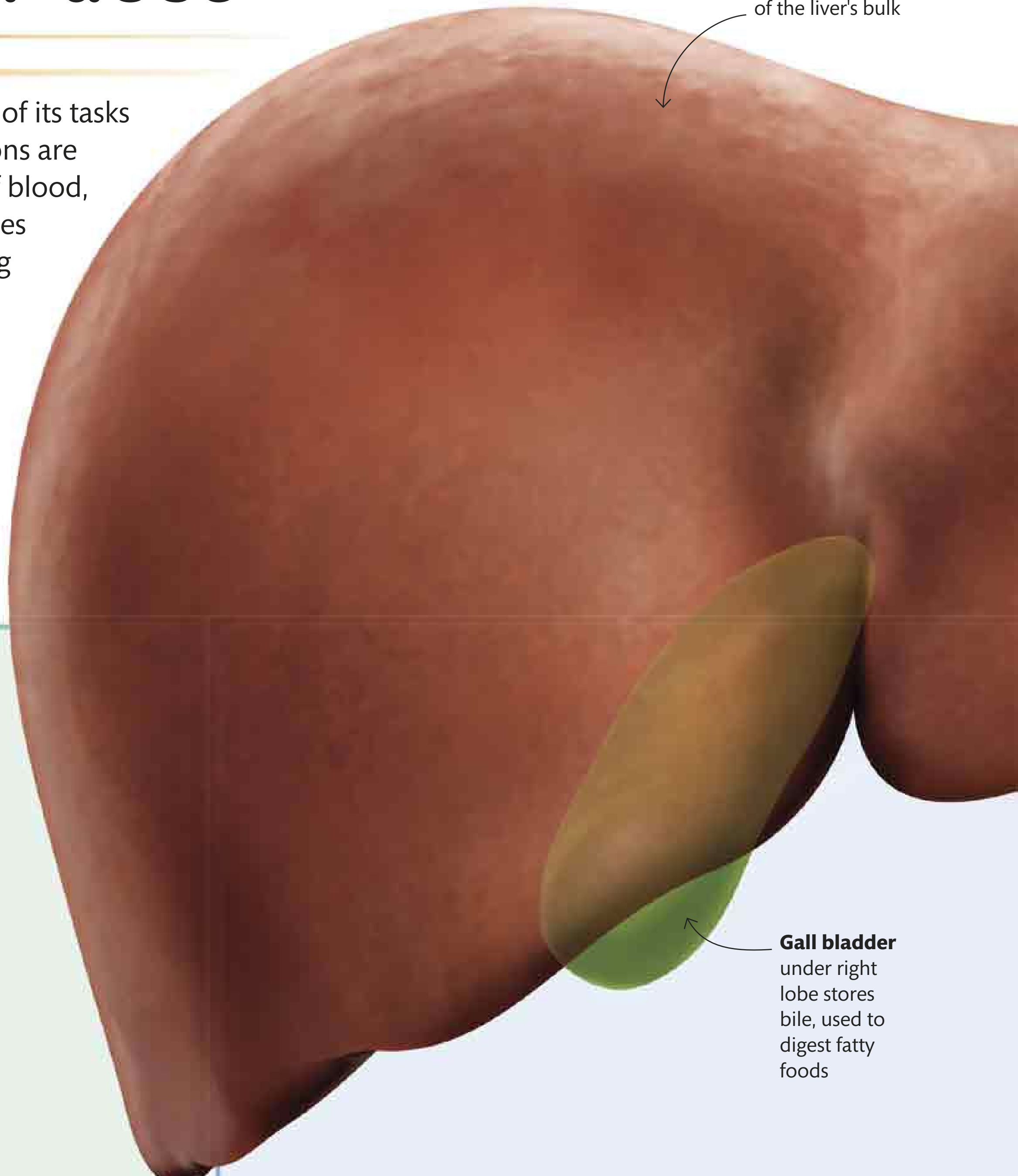
"Running a **marathon** uses as much **energy** as is contained in **12 slices** of **pizza**"

Defying the dunes

Competitors in the Sahara ultra-marathon have to cover 250 km (155 miles) of desert in six days. With temperatures above 40°C (104°F), they must make sure they drink enough to replace water lost as sweat.

DETOX CENTRAL

What the liver does



The liver is a true super-organ, and a list of its tasks would fill this whole book. Its many functions are mostly to do with adjusting the contents of blood, maintaining the levels of essential substances such as glucose and vitamins, and removing possibly harmful chemicals, or toxins.

SUPER STOREHOUSE

Almost one-third of the body's blood flows through the liver every minute. About one-quarter of this flow comes along two massive hepatic arteries. The rest arrives along the hepatic portal vein from the intestines. This blood is loaded with nutrients.

BREAKDOWN

The liver acts on many substances to break them into smaller, simpler pieces, in a process known as catabolism. In particular, it detoxifies the blood, which means changing possible toxins or poisons, such as the waste product ammonia, into harmless substances.

Hormones
Several hormones are taken apart, in particular insulin, which affects blood glucose levels.

Toxins
Harmful chemicals in body wastes, and those in foods and drinks, are split apart or changed to make them safe.

Blood cells
Dead or dying red blood cells are taken to pieces and their parts, especially iron, are recycled.

Germs
Specialized white cells in the liver, called phagocytes, attack and destroy germs.

STORAGE

Supplies of many vital substances, such as glucose, are kept in the liver. These are released when their levels in the body fall too low. The liver stocks up on these supplies again using the digested food nutrients brought in from the intestines by the hepatic portal vein.

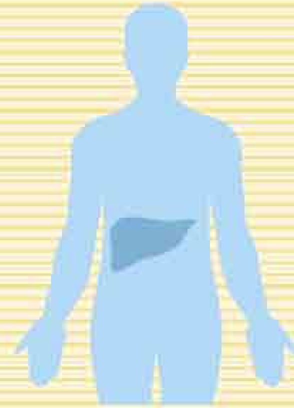
Glycogen
This is a form of carbohydrate made from joined-up glucose (sugar) units.

Minerals
These include iron needed for blood cells and copper for bones and connective tissues.

“The liver performs around 500 functions”

Left lobe arches over stomach

AT A GLANCE



- **SIZE** Length 24–26 cm (9 ½–10 in); height 7–8 cm (2 ¾–3 in); weight 1.5–1.7 kg (3–4 lb)
- **LOCATION** Almost fills the upper abdomen
- **FUNCTION** Stores many substances, regulates blood content, and breaks down toxins

Bile
Liver makes bile, stored in the gall bladder and released into the intestines.

Fats
Some kinds of fats are held in store in the liver as reserves of energy.

Vitamins
The liver can store two years' worth of vitamin A.

Nutrients
A variety of nutrients come and go, including those for making proteins.

BUILDING UP

The liver is a living chemical production factory that assembles small, simple building substances into bigger ones. This process is called anabolism. Examples include the blood chemicals needed for clotting and liver hormones that affect the production of blood cells.

Heparin
This natural substance affects the clotting ability of blood and its germ-fighting abilities.

Nutrients
Building-block substances include triglycerides to make the protective membranes around cells.

Protein synthesis
Amino acids are joined in various ways to construct many kinds of proteins for cells and tissues.

Heat
As with the heart and the kidneys, the liver is always busy and a constant source of body warmth.

BLOOD SUGAR CONTROL

Controlled by hormones such as insulin, the liver is the storehouse for blood glucose, which is needed by every cell for energy. If glucose levels fall, the liver breaks down its stores of glycogen (starch) into glucose, which dissolves into the bloodstream. If there is too much glucose, for example after too much sugary drinks or foods, the liver does the reverse and converts the extra glucose back into glycogen.

PURIFICATION PLANT

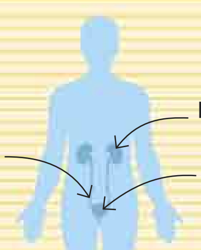
What kidneys do

As blood flows past cells and through tissues, it collects more than 100 kinds of waste and any excess sodium, blood sugar, and water. Blood then travels to the two kidneys, taking five minutes to pass through them. Here, waste and excess substances are made into a liquid called urine. The urine trickles along two tubes called ureters, one from each kidney, down to a storage bag – the bladder – and out of the body.

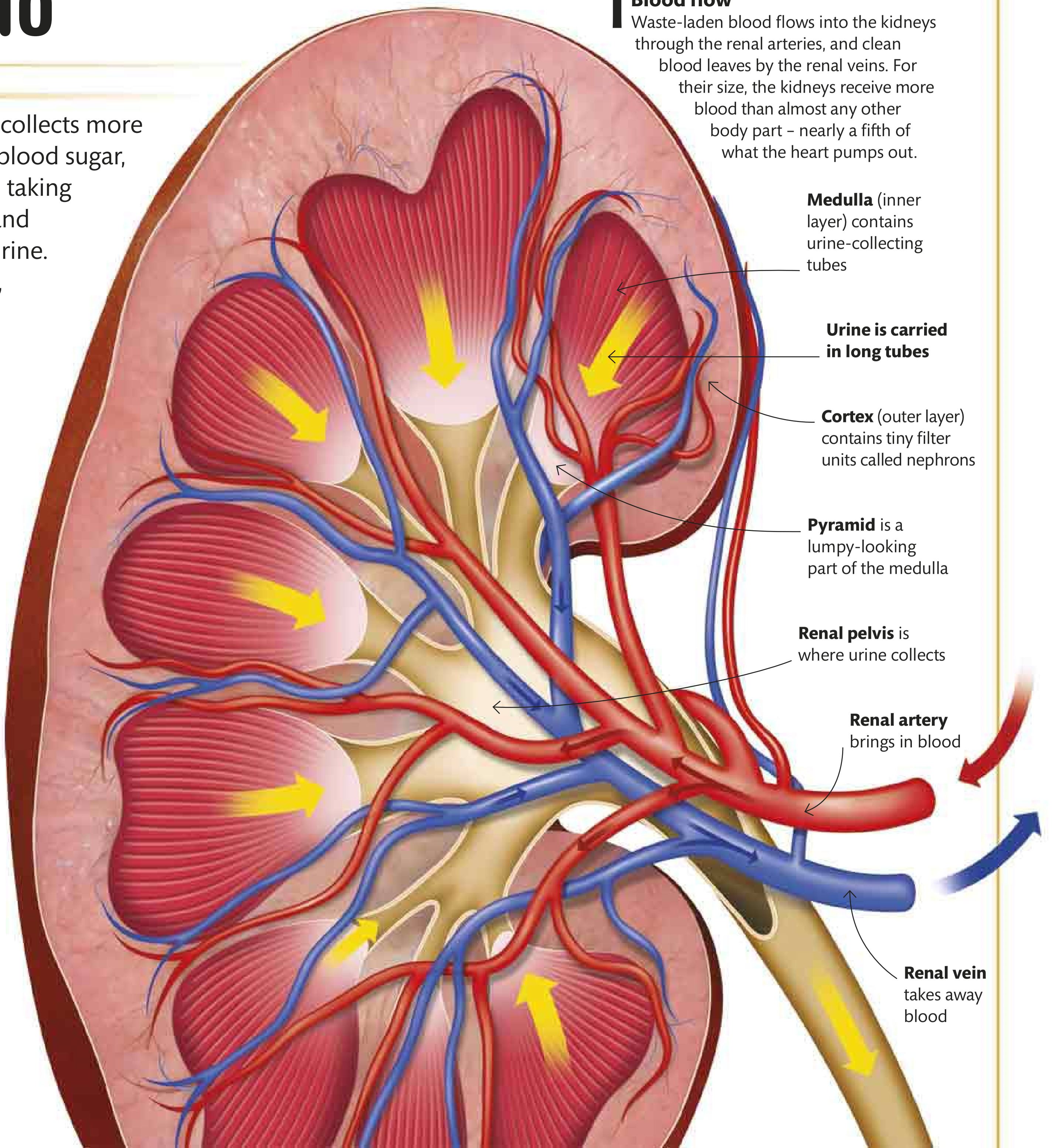
WASTE COLLECTION

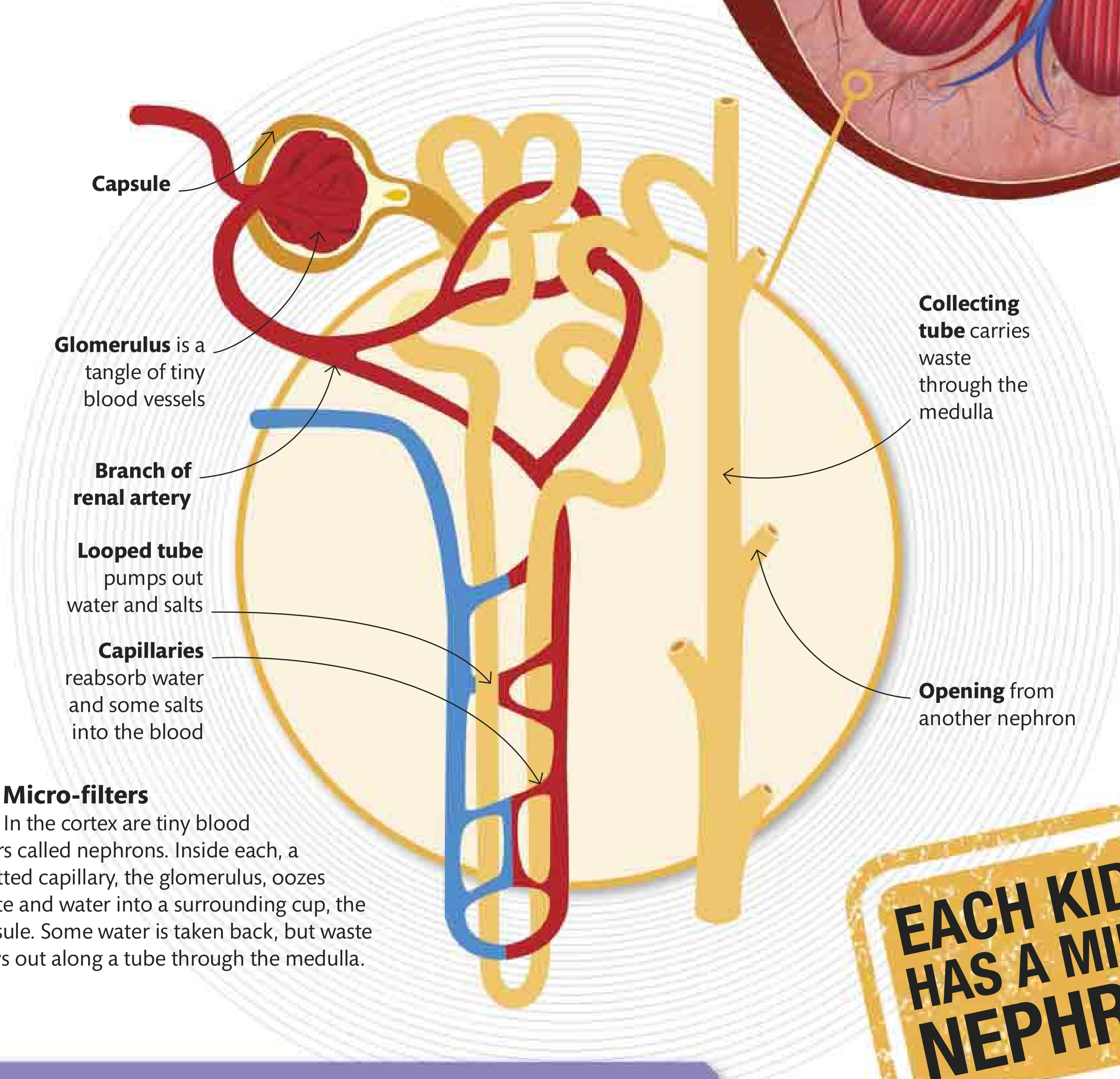
Inside its tough covering, each kidney is split into three layers: the outer cortex, the inner medulla, and a space called the renal pelvis. Urine is made in the cortex and carried by tubes into the renal pelvis. From here it flows along the ureter to the bladder.

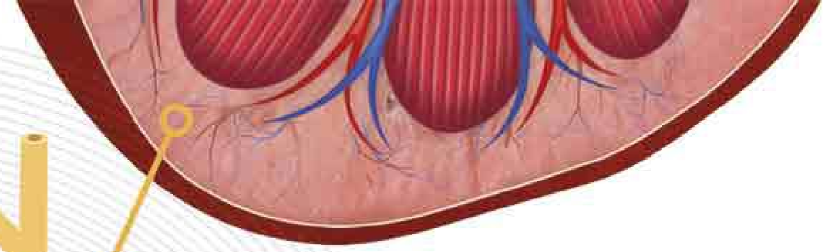
AT A GLANCE



- **SIZE** Length of each kidney 12 cm (4 ¾ in); weight 150 g (5 ¼ oz); bladder 500 ml (17 fl oz) when full
- **LOCATION** Kidneys behind liver and stomach; bladder in lower front abdomen
- **FUNCTION** Kidneys filter wastes from blood, make hormones; bladder stores urine





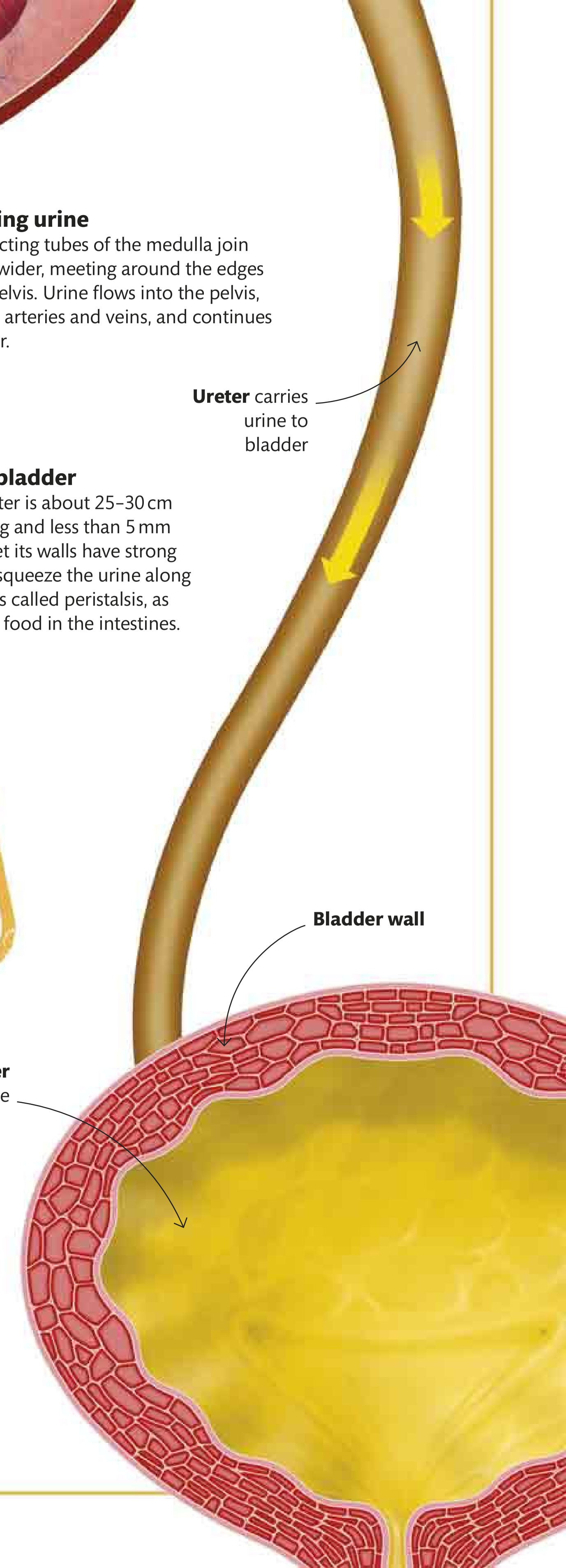


2 Micro-filters
In the cortex are tiny blood filters called nephrons. Inside each, a knotted capillary, the glomerulus, oozes waste and water into a surrounding cup, the capsule. Some water is taken back, but waste flows out along a tube through the medulla.

3 Collecting urine
The collecting tubes of the medulla join and become wider, meeting around the edges of the renal pelvis. Urine flows into the pelvis, past the main arteries and veins, and continues into the ureter.

4 To the bladder
Each ureter is about 25–30 cm (10–12 in) long and less than 5 mm (¼ in) wide. Yet its walls have strong muscles that squeeze the urine along by the process called peristalsis, as happens with food in the intestines.

EACH KIDNEY HAS A MILLION NEPHRONS



5 Super elastic
Urine dribbles through a ring of muscles into the bladder. This stretchy bag enlarges as more urine arrives. Its muscular walls squeeze to push urine out through a lower ring of muscles into a tube, called urethra, that leads outside.

STATS AND FACTS

BLOOD CLEANSING

1 2 3 4 5 6 | 1 2 3 4 5 6

OLYMPIC SWIMMING POOL

45 MILLION LITRES
(95 million pints) of blood flow through the kidneys in a lifetime (equivalent to 18 Olympic swimming pools)

BLADDER LENGTH

5 cm
(2 in)
when empty

12 cm
(4 ¾ in) or more
when full

WATER IN URINE
95 PER CENT


6

DEFENCE AND CONTROL

Our bodies are not only ideal for us – they are also an attractive home for other organisms. To keep them out, an internal army is ready around the clock to fight invaders. Meanwhile, hormones ensure the smooth operation of almost every internal process, from energy use to the thrill of fear.

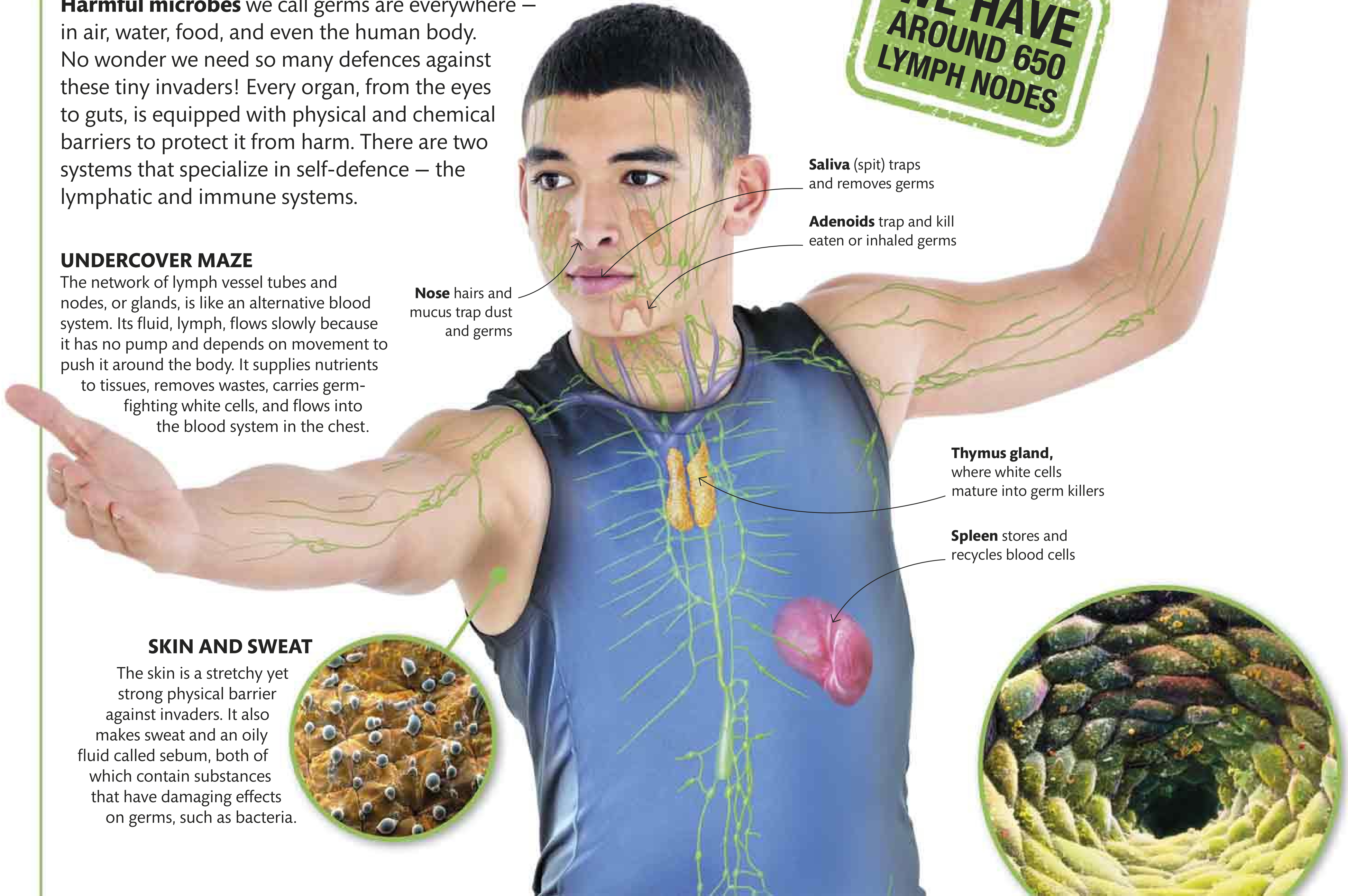
SECURITY ALERT

Protecting the body

Harmful microbes we call germs are everywhere – in air, water, food, and even the human body. No wonder we need so many defences against these tiny invaders! Every organ, from the eyes to guts, is equipped with physical and chemical barriers to protect it from harm. There are two systems that specialize in self-defence – the lymphatic and immune systems.

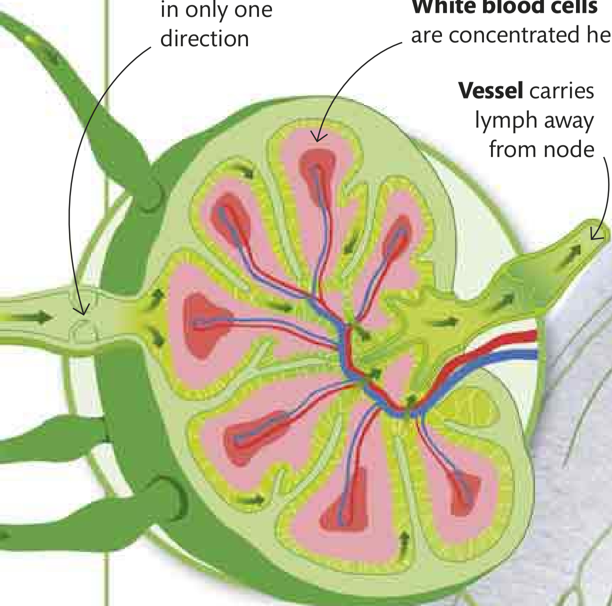
UNDERCOVER MAZE

The network of lymph vessel tubes and nodes, or glands, is like an alternative blood system. Its fluid, lymph, flows slowly because it has no pump and depends on movement to push it around the body. It supplies nutrients to tissues, removes wastes, carries germ-fighting white cells, and flows into the blood system in the chest.



SKIN AND SWEAT

The skin is a stretchy yet strong physical barrier against invaders. It also makes sweat and an oily fluid called sebum, both of which contain substances that have damaging effects on germs, such as bacteria.



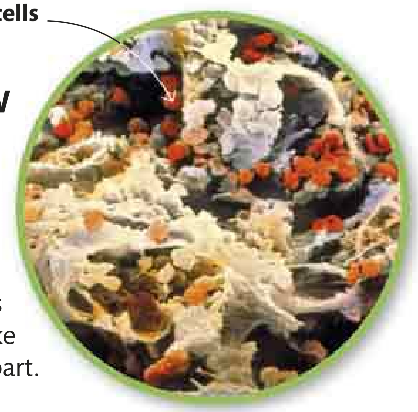
LYMPH NODES

These small, bean-like glands are spread all over the body, with clusters in places such as the armpits and groin. They are full of white cells that are ready to attack germs and other invaders.

STOMACH

The stomach lining produces hydrochloric acid and strong digestive juices containing enzymes to break down food. These chemicals also kill or disable any germs swallowed with food and drink.

Lymph vessel (lymphatic)



BONE MARROW

As well as making new red cells, the jelly-like bone marrow also produces white cells. Some white cells eat germs, while others make substances called antibodies that stick to germs and make them inactive or split apart.

Lymph fluid renews daily

STATS AND FACTS

RATE OF FLOW

BLOOD **75** ml/sec (2.57 fl oz/sec)

LYMPH **15** ml/sec (0.51fl oz/sec)

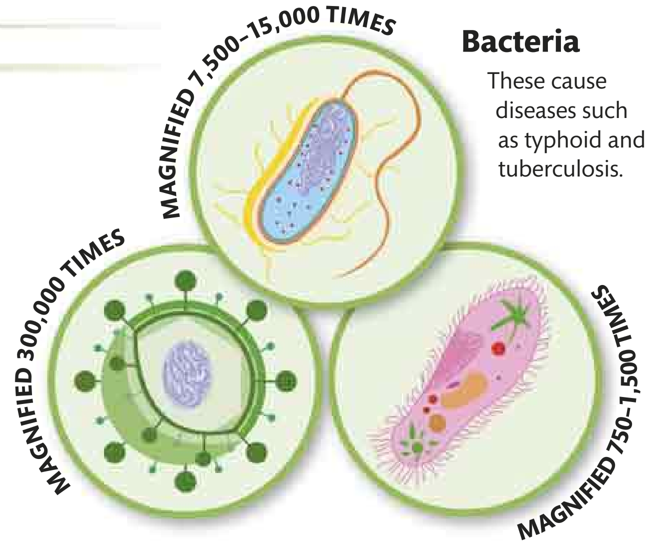
LYMPH NETWORK

If all the lymph vessels were put end to end, they would stretch around the world two-and-a-half times

ON THE ATTACK

Combating germs

Despite the body's super-tough defence barriers – from the skin to stomach acid – germs sometimes get inside. But the invaders are nearly always doomed because they are attacked by the armed forces of the immune system – white blood cells. There are more than 20 main types of white cells, and they work together like a crack assault team to destroy germs. One way they do this is by producing natural weapons called antibodies. Tinier than any of the invaders, billions of antibodies cause them to clump together, stop working, spill out their insides, or even explode!



Bacteria

These cause diseases such as typhoid and tuberculosis.

Viruses

These cause diseases such as the flu, common cold, measles, and mumps.

Protists

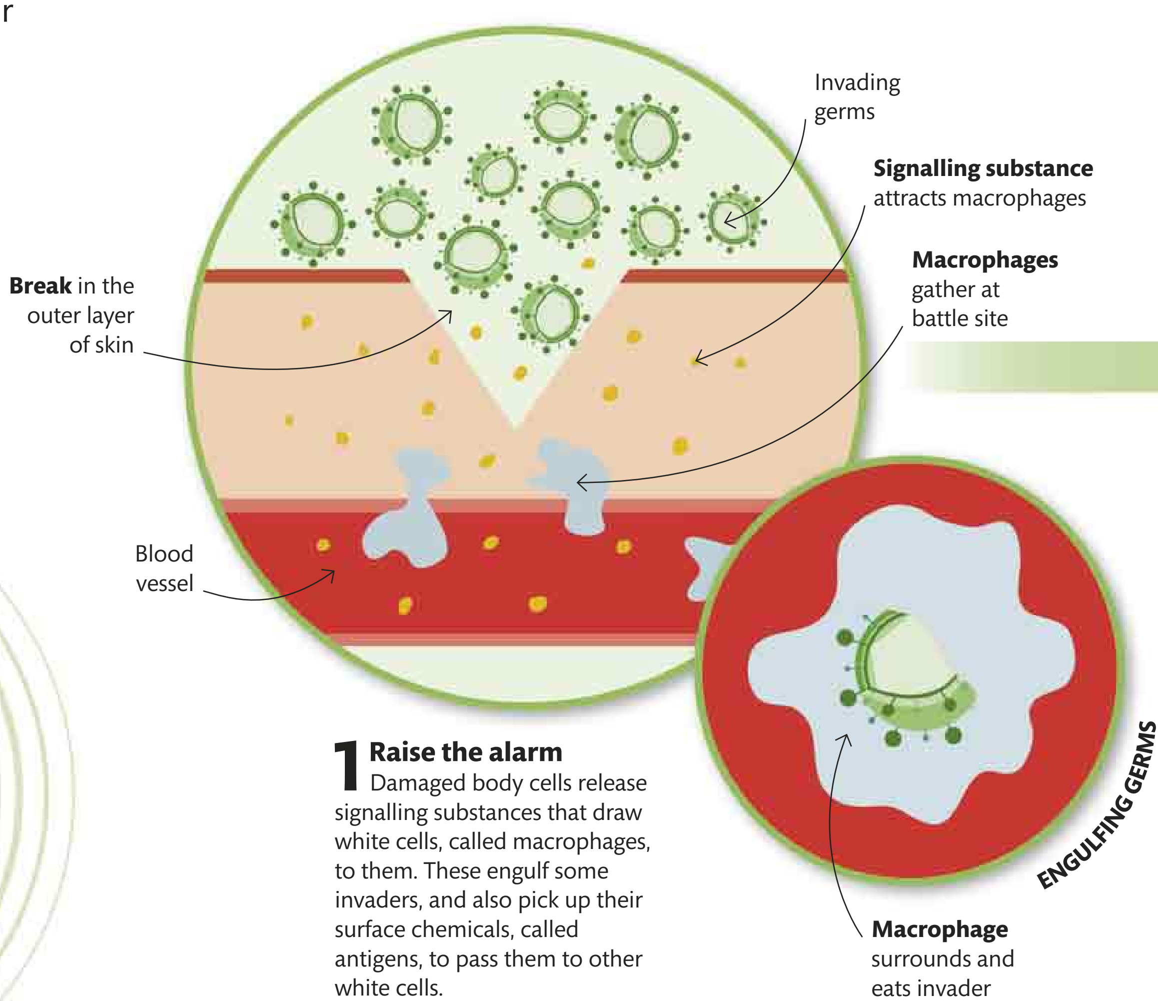
These cause diseases such as malaria and sleeping sickness.

BODY INVADERS

Single-celled germs, called protists, are similar in size and structure to body cells. Bacteria are many times smaller – you need a microscope to see them – and much simpler inside. Even tinier are viruses – around 100 times smaller than a bacteria. They have even less inside them, consisting only of short lengths of genetic material encased in a protein shell.

GERM WARFARE

Any break in the protective outer layer of dead skin allows germs to get into tissues. Once inside, they damage cells, take nutrients from them, and multiply. If they enter the skin's blood vessels, they can spread around the body in minutes. So white cell defences must gather fast at the war zone, ready for action.



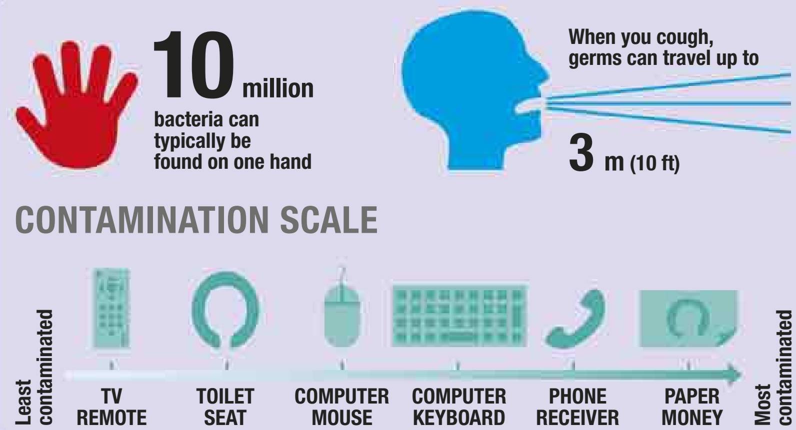
1 Raise the alarm
Damaged body cells release signalling substances that draw white cells, called macrophages, to them. These engulf some invaders, and also pick up their surface chemicals, called antigens, to pass them to other white cells.

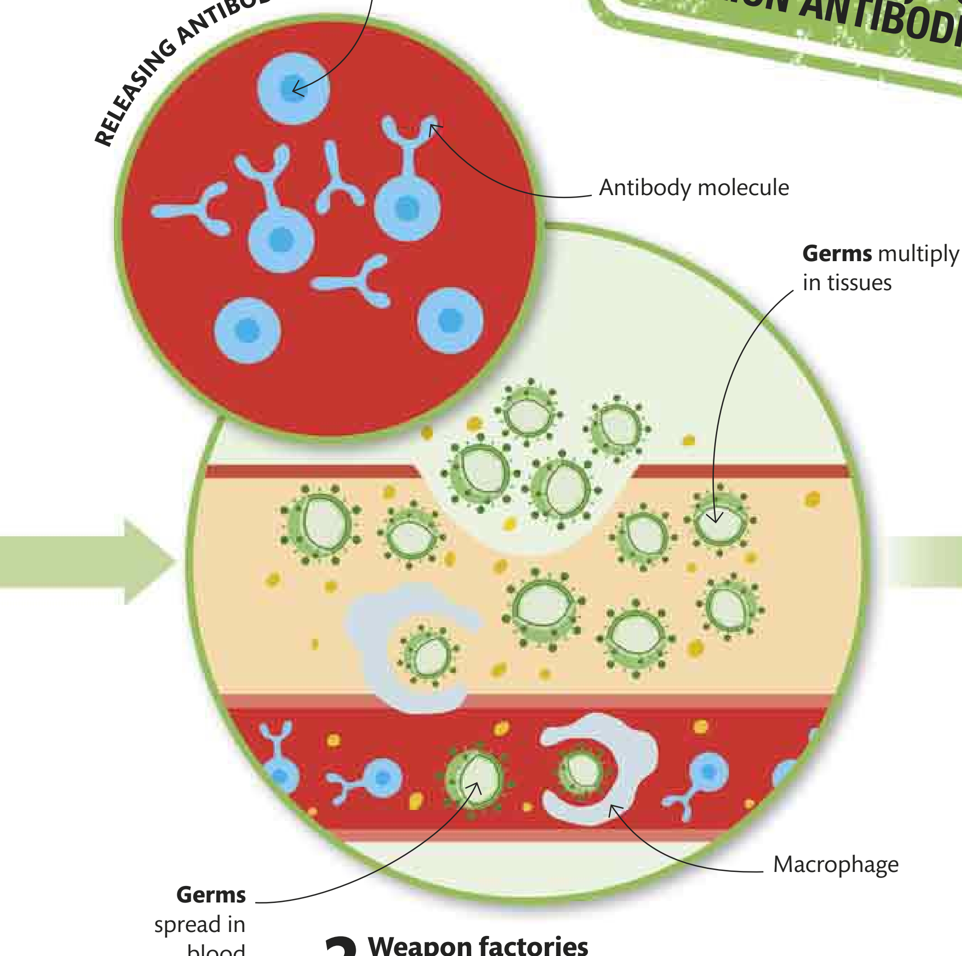
> **"All the white blood cells together weigh twice as much as the brain"**

ALLERGIES

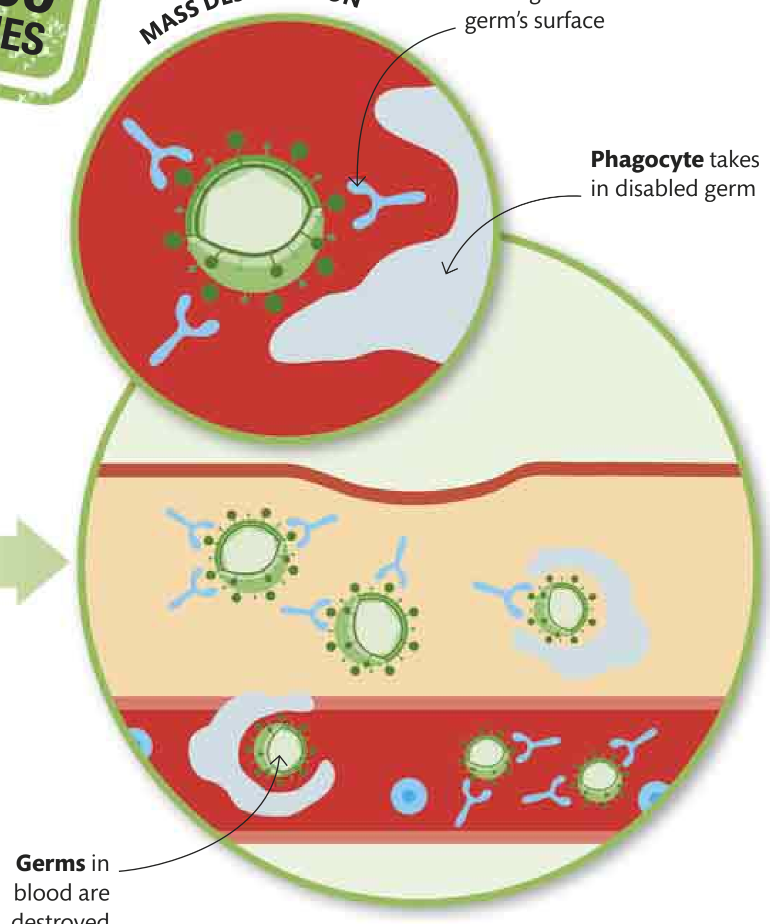
The immune system is designed to defend against germs and other harmful threats. But sometimes it attacks usually harmless substances, such as those in animal fur or feathers, plant pollen, or house dust. This reaction can cause an allergy, which includes itchy watery eyes, red itching skin, or wheezy breathing. Medicines can reduce these symptoms.

STATS AND FACTS

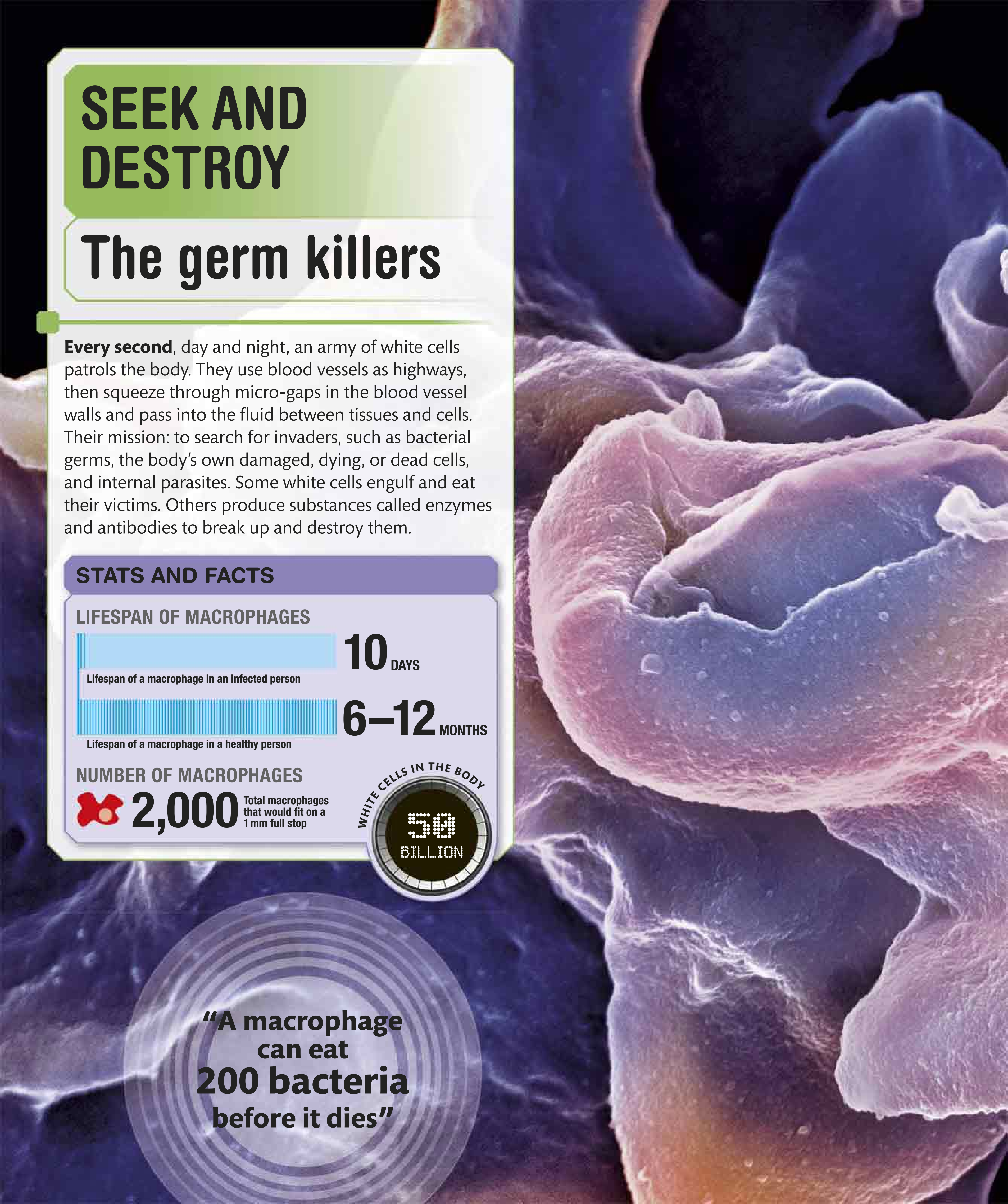




2 Weapon factories Macrophages carry the antigens of the invaders to other white cells, known as plasma B cells. These turn into weapon factories and produce incredible amounts of Y-shaped antibodies, up to 10,000 per cell per second!



3 Invaders defeated Different B cells produce different antibodies, each tailor-made to stick on to certain kinds of germs, disabling, clumping, or dissolving them. Their remains are swallowed by white cells called phagocytes, which include macrophages.



SEEK AND DESTROY

The germ killers

Every second, day and night, an army of white cells patrols the body. They use blood vessels as highways, then squeeze through micro-gaps in the blood vessel walls and pass into the fluid between tissues and cells. Their mission: to search for invaders, such as bacterial germs, the body's own damaged, dying, or dead cells, and internal parasites. Some white cells engulf and eat their victims. Others produce substances called enzymes and antibodies to break up and destroy them.

STATS AND FACTS

LIFESPAN OF MACROPHAGES

10 DAYS
Lifespan of a macrophage in an infected person

6–12 MONTHS
Lifespan of a macrophage in a healthy person

NUMBER OF MACROPHAGES

2,000 Total macrophages that would fit on a 1 mm full stop

WHITE CELLS IN THE BODY
50 BILLION

"A macrophage can eat 200 bacteria before it dies"

Deadly embrace

This white cell (called a macrophage, which means "big eater") is enveloping a group of rod-shaped tuberculosis bacteria in its folds. Once inside, the bacteria will be broken down into tiny pieces.

RUNNING REPAIRS

Regeneration

Even the best machines need maintenance, repair, and the occasional replacement part. The amazing living machine that is the body is no exception. Some parts, such as skin, intestine lining, and blood cells, wear out fast and need replacing rapidly – in days, or even hours. Others, such as many of the brain's nerve cells and the heart's muscle cells, last a lifetime. On a smaller scale, the internal parts of these cells are constantly maintained and mended as some of their molecules break down and are replaced. Repairs become less efficient as we age.

"Human skin is completely regenerated every four weeks"

POPPING OFF

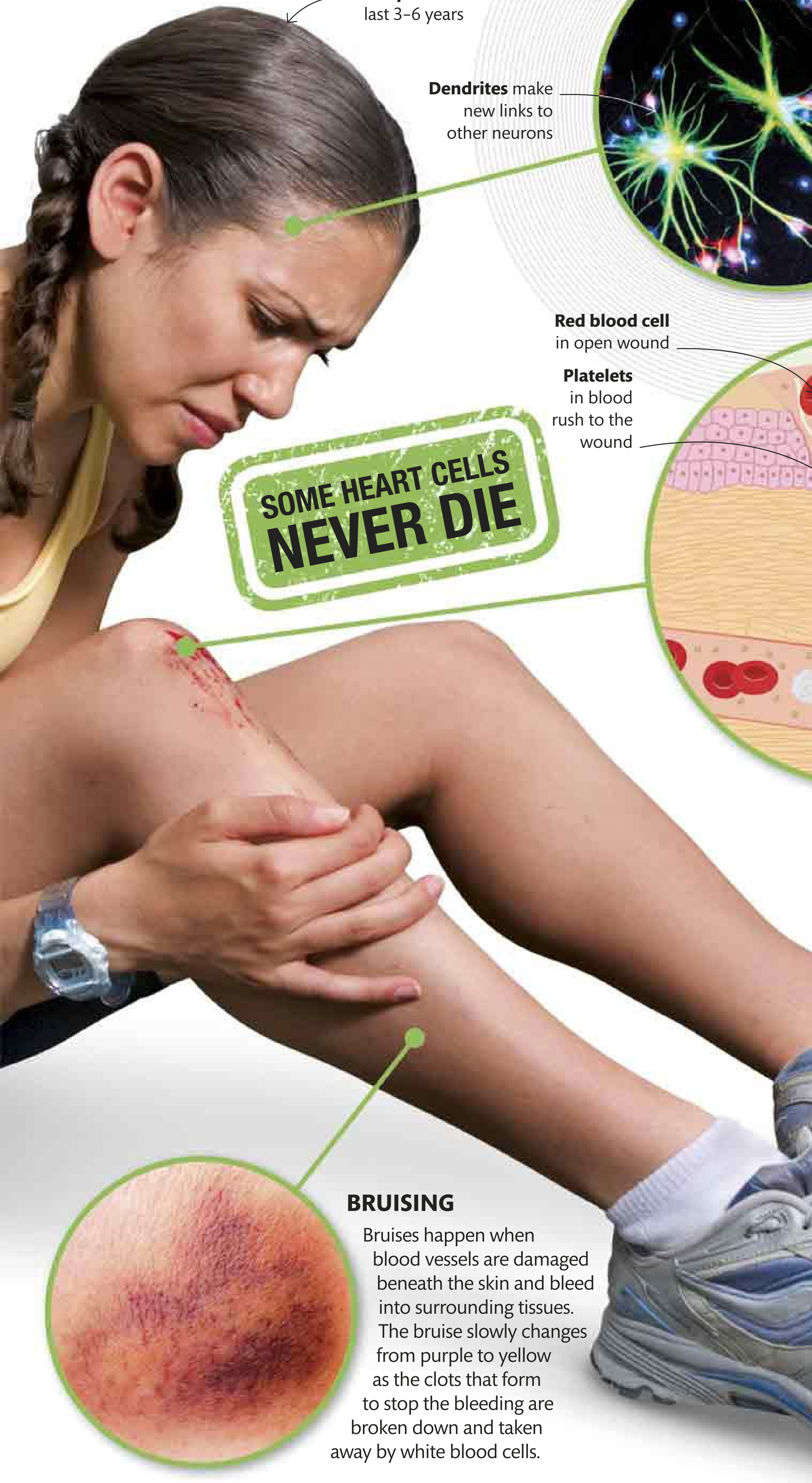
Every day, more than 50 billion cells in the body die – on purpose. Each is programmed to live for only a certain amount of time. Cells die in a highly organized way, with lumps called blebs forming on the surface (shown above) that then drop off and are cleared away by scavenging white blood cells until all the cell is gone. This process is called apoptosis. It prevents the build-up of old, weak, damaged cells that would otherwise clog blood vessels, leak wastes, and cause other problems.

COPING WITH WEAR

Joints, such as the knee and elbow, cope with the greatest physical movement and wear. The smooth cartilage between the joints has only a limited ability to repair itself, so overuse can be harmful.

TOTAL TURNOVER

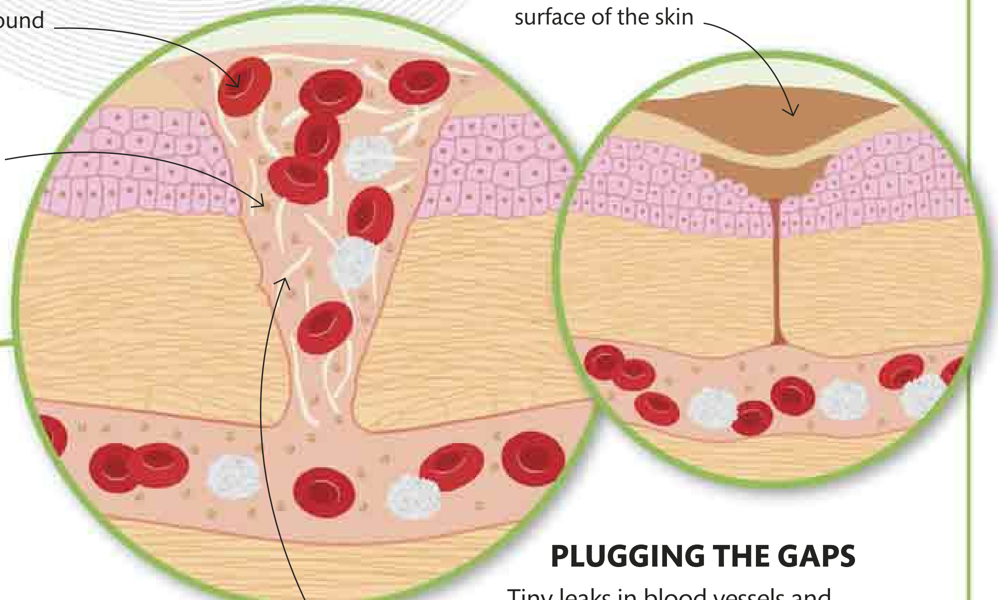
Each part of the body gets replaced at its own rate. Many of the building materials for this work come from nutrients in food, while other raw materials are recycled within the body by organs such as the liver.



INTERNAL REWIRING

The nerve cells (neurons) in the brain constantly change the connections their dendrite branches make with other nerve cells as you experience events and form new memories. However, it is much more difficult to replace neurons that are damaged by injury, although this does happen in some parts of the brain.

SOME HEART CELLS NEVER DIE



PLUGGING THE GAPS

Tiny leaks in blood vessels and tissues are rapidly plugged by a sticky mix of platelets, fibrin fibres, and blood cells, in a process called blood clotting. The clot seals any leaks and hardens into a tough lump called a scab. This holds the wound together and protects it from outside infection while the broken tissues grow back together again. The scab then falls off.

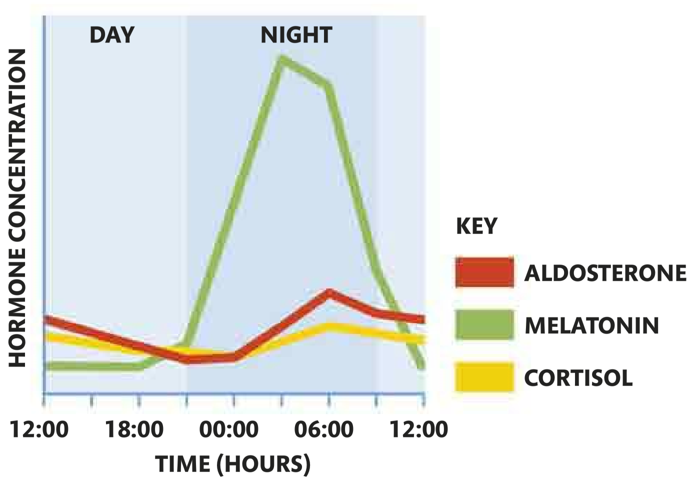
BRUISING

Bruises happen when blood vessels are damaged beneath the skin and bleed into surrounding tissues. The bruise slowly changes from purple to yellow as the clots that form to stop the bleeding are broken down and taken away by white blood cells.

BODY CONTROLLERS

How hormones work

The brain and nerves, prompted by tiny electrical nerve signals, form one of the body's two control networks. The other control system uses natural chemical substances called hormones. These are made in parts of the body called hormonal, or endocrine, glands. Hormones are released into the blood, and as each one travels around the body it targets certain organs and tissues. This remarkable system uses more than 50 main hormones, made by over a dozen major hormone glands. Hormones are also produced in organs such as the heart, stomach, and liver.

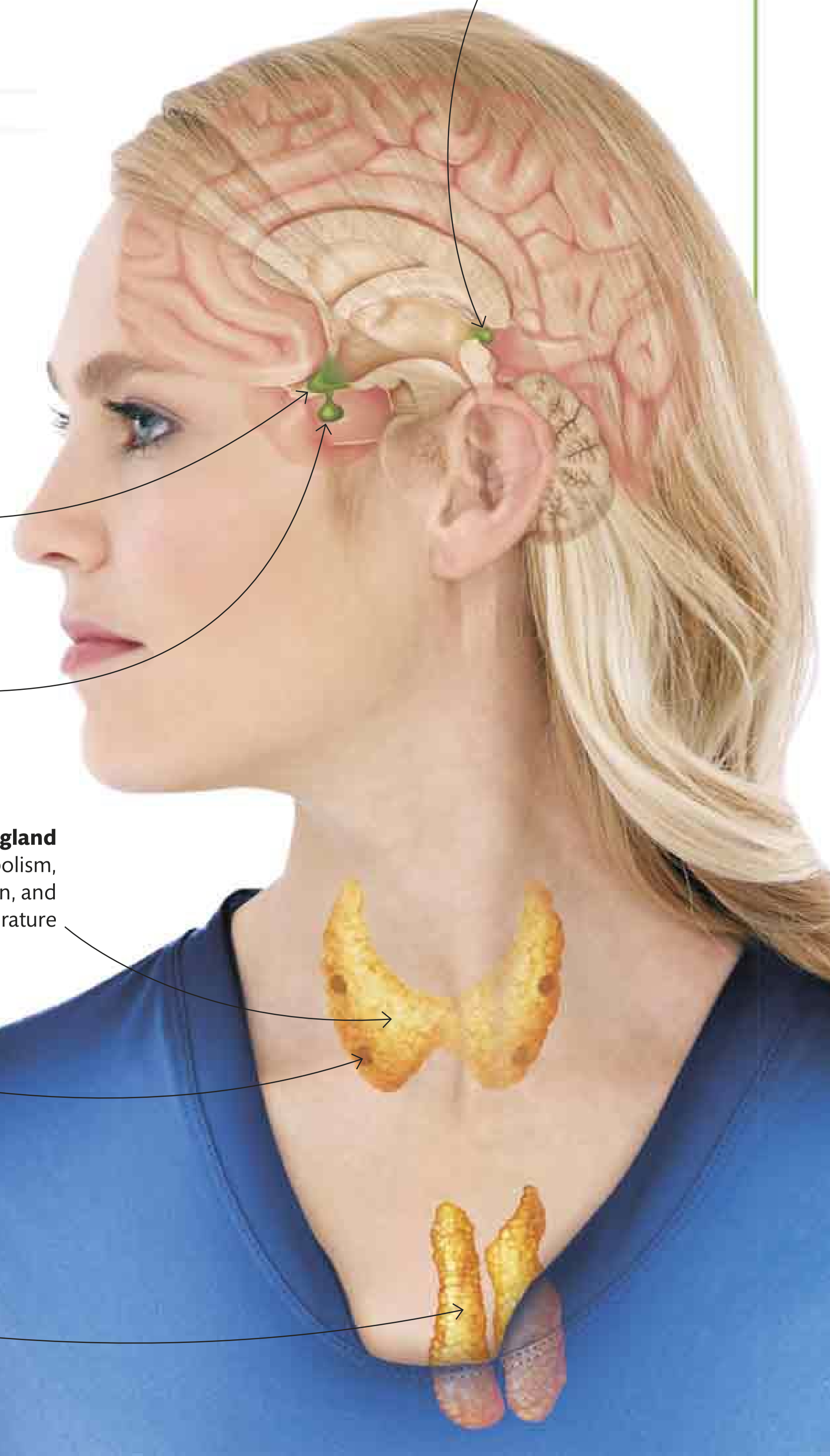


DAILY CYCLES

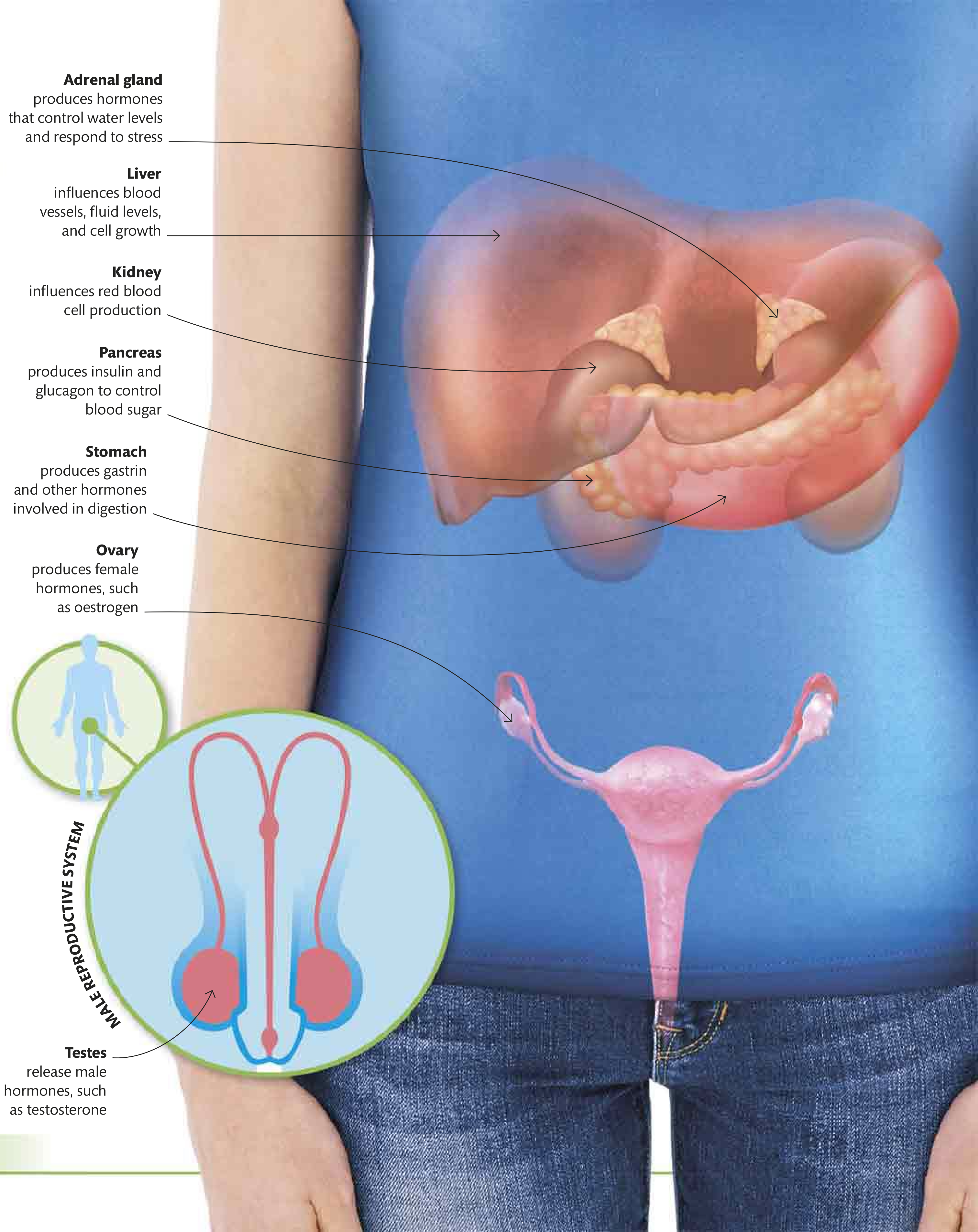
The level of each hormone rises and falls in a regular cycle over the course of a day. Melatonin increases in the evening to make you sleepy, then drops to wake you up; aldosterone regulates water levels; and cortisol lessens reactions to stress.

HORMONE MAKERS

Endocrine glands – present in the head, chest, and abdomen – pass hormones directly into the blood supply as blood flows through the glands. Hormones influence almost every cell, organ, and function of the body.



“Doctors in ancient times detected diabetes by tasting the sweetness of their patients’ urine”



BODY REGULATORS

The thyroid gland makes two vital hormones, thyroxine (T4) and tri-iodothyronine (T3). Acting as the body’s speed controllers, they increase the rate at which almost all cells and systems work, particularly:

Heart and vessels
They make the heart pump faster and more powerfully, increasing its output and the speed of blood flow.

Digestive system
The stomach produces more digestive juices and enzymes, and food moves through the gut faster.

Liver
The liver increases its processing speed of nutrients, minerals, blood cells, and other substances.

Proteins
These building blocks of cells and tissues are built up and broken down more rapidly.

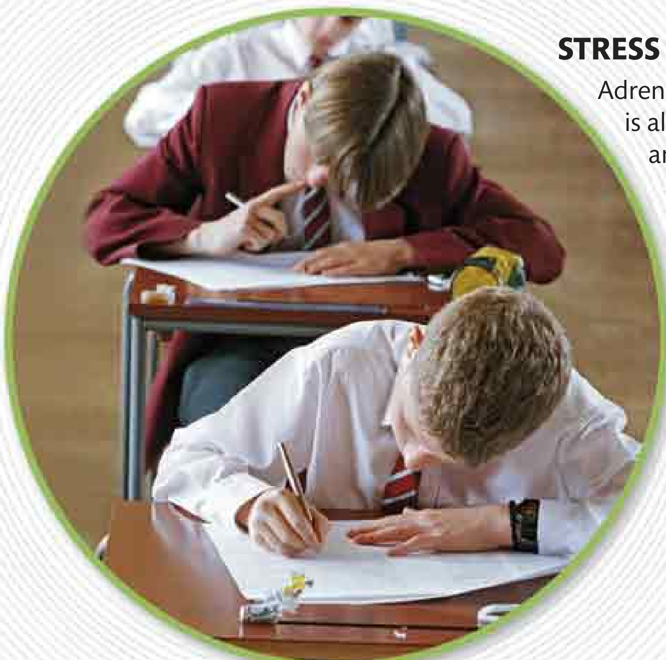
Cells and tissues
More nutrients are taken in and more waste products produced. There is a general increase in energy use.

DANGER, DANGER!

Stress hormones

From worries that nag for days, to sudden shock – the body copes with stress in many ways. Hormones are the body's chemical messengers and they play an important role in keeping you calm, yet ready for action. The adrenal glands, which sit on top of the kidneys, make several stress hormones. Cortisol affects levels of blood glucose (sugar), reduces pain and swelling, increases tissue repair, and delays the body's response to injury or infection. Adrenaline also affects blood glucose levels and prepares the body to face danger – the fight or flight reaction.

"Adrenaline makes you perceive things you see twice as fast as normal"



STRESS AND THE BRAIN

Adrenaline's relative, noradrenaline, is also made in the adrenal glands and has similar affects. It is produced in the nervous system, too, where it passes messages between nerve cells (neurons). It is particularly important for tasks that involve concentrating for long periods and focusing without distractions or daydreams, such as when you are studying for an exam.

AT A GLANCE

- **LOCATION** Adrenal glands sit on top of kidneys
- **SIZE** Height 2 cm (¾ in); length 8 cm (3 in); weight 5–6 g
- **FUNCTION** The adrenal glands produce hormones, including the stress hormones, cortisol, adrenaline, and noradrenaline, as well as those affecting urine production.

ADRENALINE KICK

As soon as the brain recognizes a threat – real or imaginary, planned or unexpected – it tells the adrenal glands to release adrenaline. The hormone floods through the blood network in seconds and, working with the nervous system, affects the entire body.

"Adrenaline levels are lowest while dreaming"

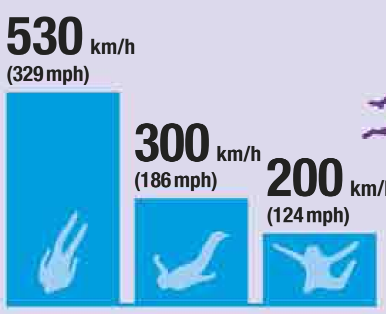
THRILLS AND SPILLS

Adrenaline rush

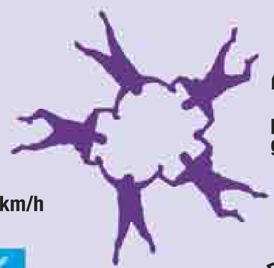
There's nothing quite like the rush of excitement you get when taking part in something that involves speed or taking risks, such as skiing, snowboarding, mountain-biking, or skydiving. This thrilling feeling is a result of the hormone adrenaline, released when the body is facing possible danger. High-energy sugar floods into the blood and enters cells, speeding up their processes and, in turn, the heart, putting both body and mind on edge.

STATS AND FACTS

FREEFALL SPEEDS



FORMATION SKYDIVE



400 people, largest group freefall

AGE OF OLDEST SKYDIVER **101**

Daredevil diving

A skydiver leaps from a plane with only a parachute to save him. He freefalls for around a minute, supported only by the air pushing upwards, before opening his parachute to glide safely back to Earth.

"The highest ever freefall was from 39 km (24 miles) above ground"


7

NEW LIFE AND GROWTH

Incredibly, every human starts life as just one cell. To turn into an adult with trillions of cells involves an amazing process of growth and development. Learning how to use and coordinate all the body's systems takes years of practice. Becoming a superhuman is not an easy process!

MAKING A SUPERHUMAN

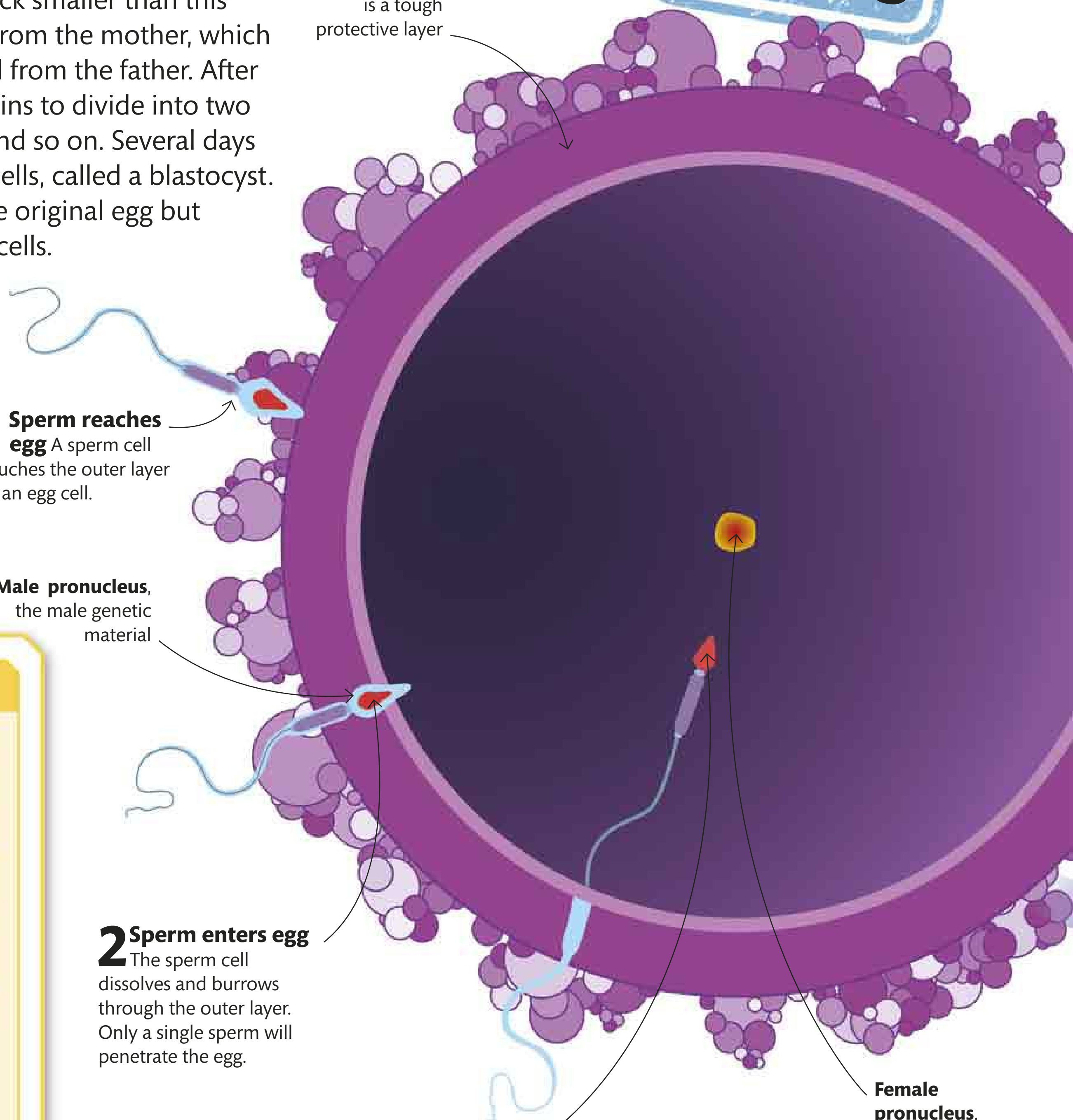
First week of life

SPERM CAN SURVIVE UP TO 5 DAYS

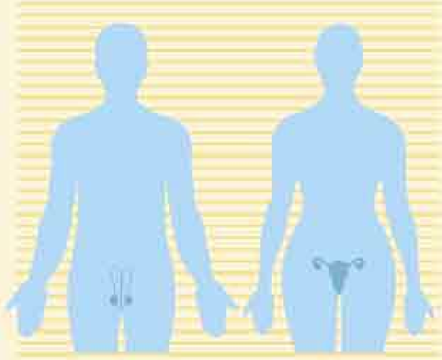
Every amazing human body, with its billions of cells, begins as a single cell – a tiny speck smaller than this full stop. The speck is an egg cell from the mother, which has been fertilized by a sperm cell from the father. After a few hours, the fertilized egg begins to divide into two cells, then four cells, then eight, and so on. Several days later it becomes a hollow ball of cells, called a blastocyst. It is still about the same size as the original egg but it now consists of more than 300 cells.

SPERM MEETS EGG

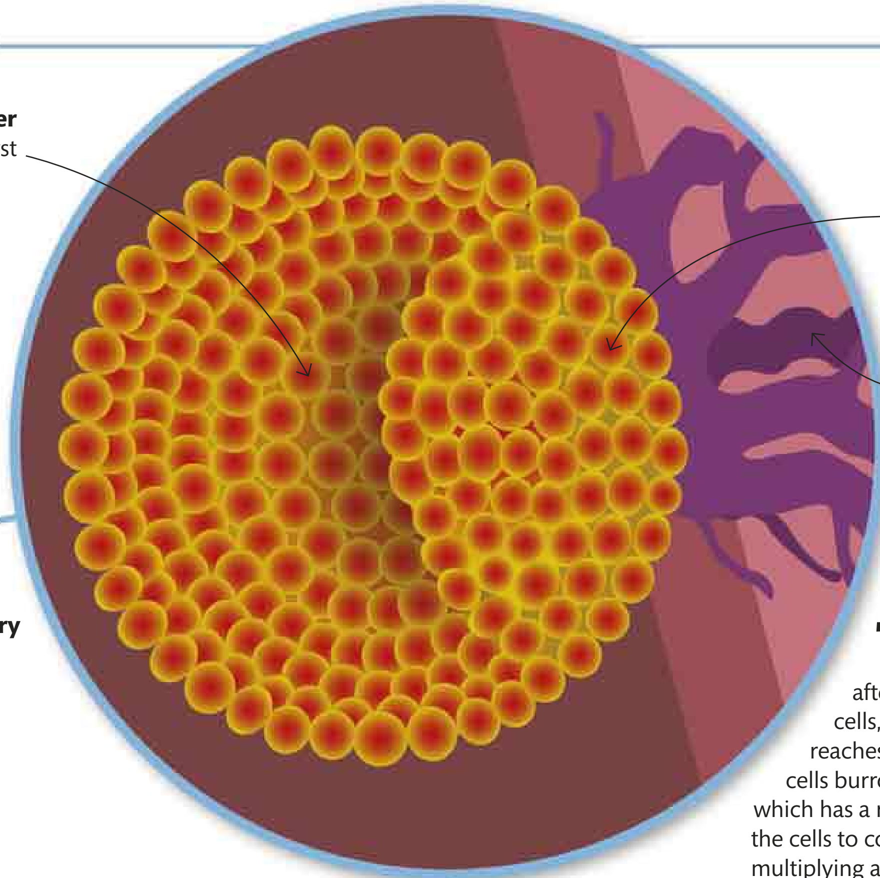
Of the millions of sperm, swimming by lashing their tails, only a few hundred make it to the relatively huge egg. Only one sperm manages to get through the egg's tough outer layer to the inside, where its genetic material joins with the genetic material of the egg.

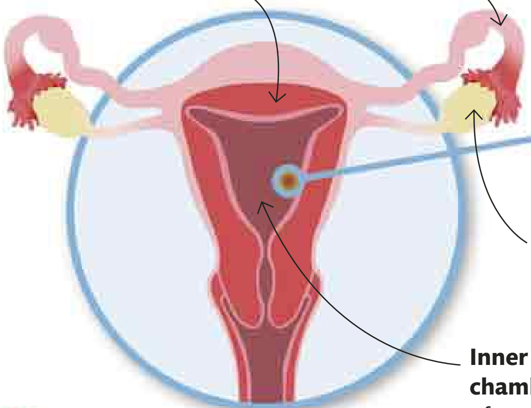


AT A GLANCE

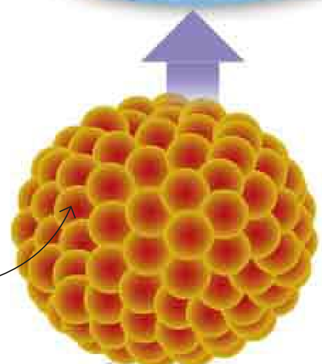


- **SIZE** Testes 5 cm (2 in) long; ovary 4 cm (1½ in) long, womb 8 cm (3 in) long
- **LOCATION** Male parts hang outside body; female parts are in the lower abdomen
- **FUNCTION** Reproduction by making sperm and egg cells; also make male and female hormones

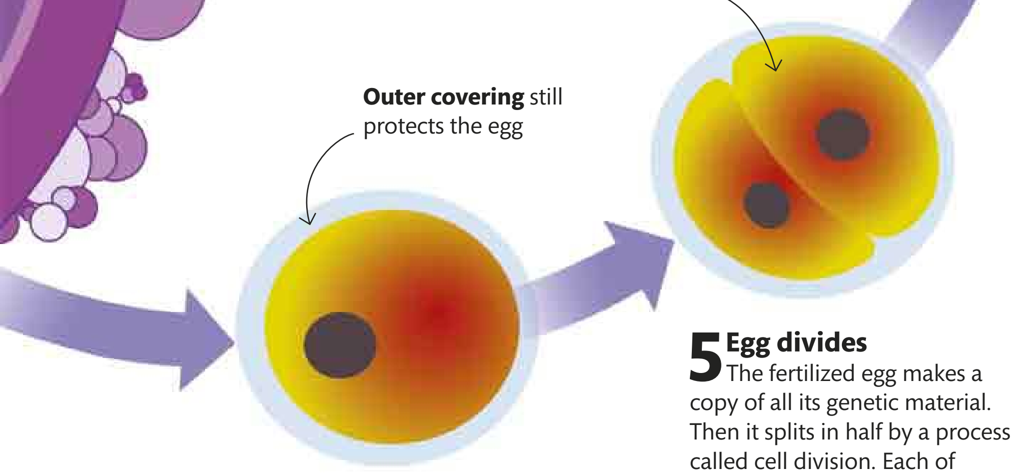




7 In the womb
About five to six days after fertilization, the ball of cells, now called a blastocyst, reaches the womb. Some of its cells burrow into the womb lining, which has a rich blood supply, enabling the cells to continue dividing and multiplying and grow into an embryo.



6 Ball of cells
Another two or three days of cell division results in a ball of cells called a morula. Since this is still the same size as the original egg, the individual cells are now much smaller, each about the size of a normal body cell.

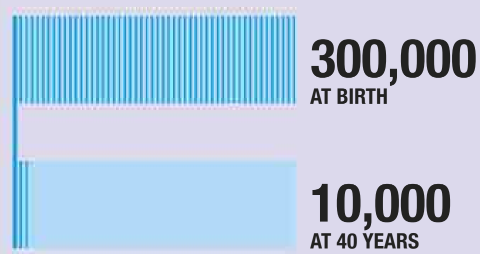


4 Fertilized egg
The two sets of genetic material combine to make a complete set. At this stage, the egg is floating slowly along the fallopian tube – on its way from the ovary, from where the eggs are released, to the womb.

5 Egg divides
The fertilized egg makes a copy of all its genetic material. Then it splits in half by a process called cell division. Each of these two new, smaller cells receives one complete set of genetic material.

STATS AND FACTS

EGG CELL STATISTICS



EGG AND SPERM SIZE

IN THE WOMB

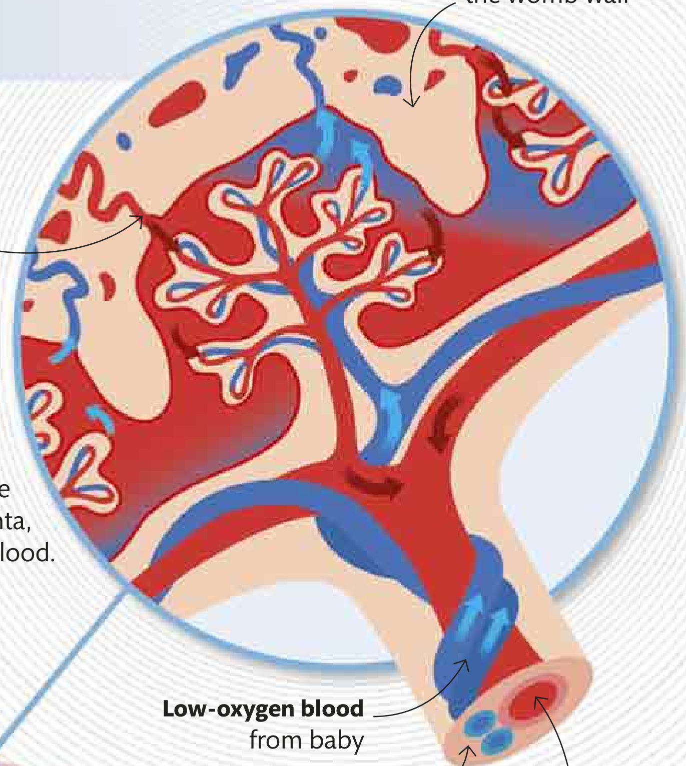
Life before birth

After just one week, the tiny human embryo – as small as the dot on this i – settles into the womb lining. Here it begins to grow and develop at an astonishing rate. Parts start forming – first the brain and the head, then the main body, followed by the arms and legs. By two months, all the main organs, including the eyes, beating heart, silent lungs, and twitching muscles, have formed – even though the embryo is smaller than a thumb.

LIFE SUPPORT SYSTEM

The baby cannot breathe or eat in the womb. Oxygen and nutrients from the mother's blood pass through thin membranes, inside the disc-shaped placenta, to the baby's blood.

Mother's blood vessels in placenta



Placenta embedded in the womb wall

Low-oxygen blood from baby

Umbilical cord to baby

High-oxygen blood to baby

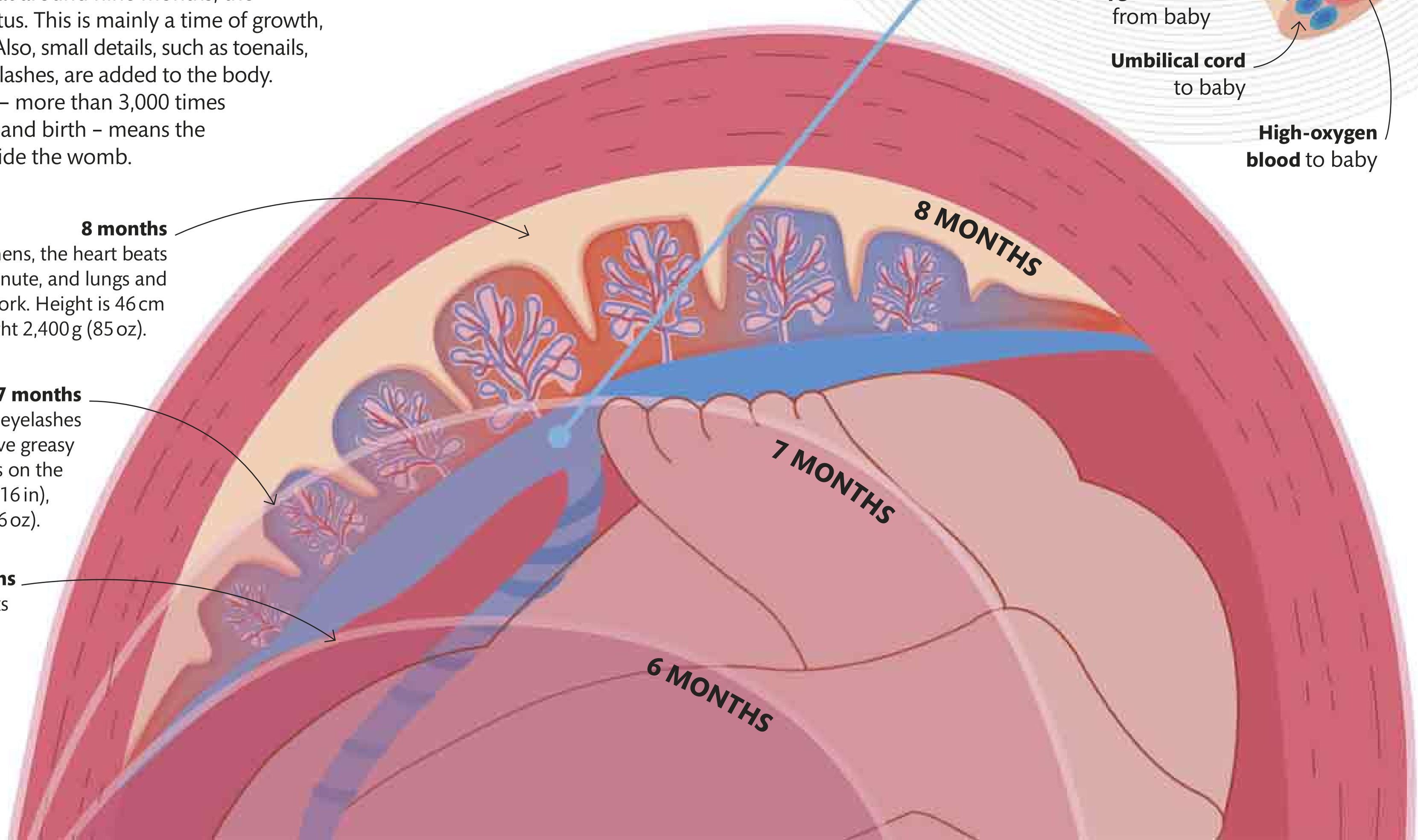
SQUEEZED FOR SPACE

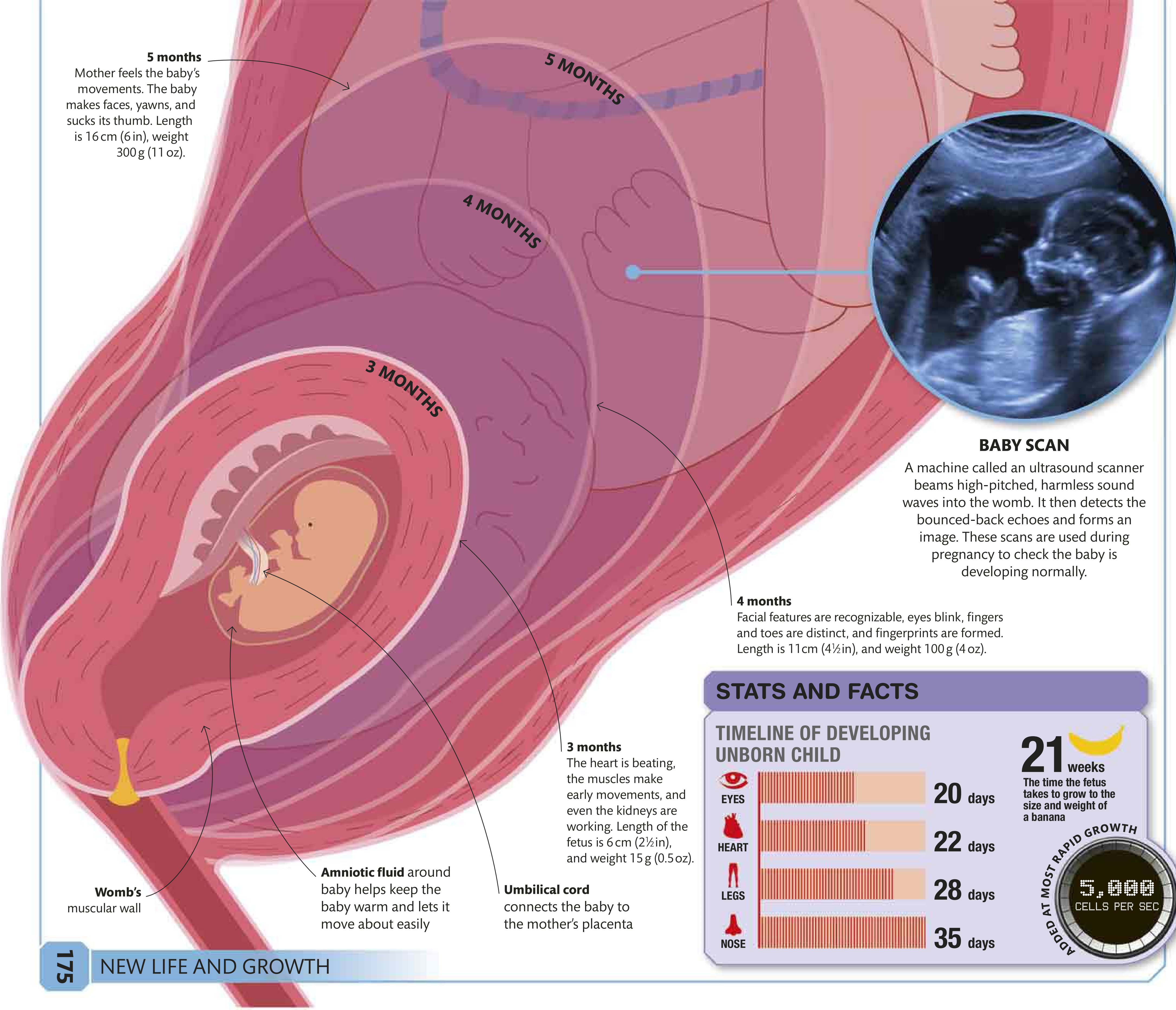
From two months until birth at around nine months, the developing baby is called a fetus. This is mainly a time of growth, the greatest of our whole life. Also, small details, such as toenails, fingernails, eyebrows, and eyelashes, are added to the body. The immense increase in size – more than 3,000 times heavier between two months and birth – means the baby becomes a tighter fit inside the womb.

8 months
Sucking reflex strengthens, the heart beats at a rate of 140 per minute, and lungs and stomach are ready to work. Height is 46 cm (18 in), weight 2,400 g (85 oz).

7 months
Scalp hair, eyebrows, and eyelashes lengthen, and a protective greasy layer, called vernix, forms on the skin. Height is 40 cm (16 in), weight 1,300 g (46 oz).

6 months
The baby responds to noises, kicks and thumps, its body develops brown baby fat, and there is still enough room to move in the womb. Height is 35 cm (14 in), weight 650 g (23 oz).





5 months
Mother feels the baby's movements. The baby makes faces, yawns, and sucks its thumb. Length is 16 cm (6 in), weight 300 g (11 oz).

4 months
Facial features are recognizable, eyes blink, fingers and toes are distinct, and fingerprints are formed. Length is 11 cm (4½ in), and weight 100 g (4 oz).

3 months
The heart is beating, the muscles make early movements, and even the kidneys are working. Length of the fetus is 6 cm (2½ in), and weight 15 g (0.5 oz).

Womb's muscular wall

Amniotic fluid around baby helps keep the baby warm and lets it move about easily

Umbilical cord connects the baby to the mother's placenta

BABY SCAN

A machine called an ultrasound scanner beams high-pitched, harmless sound waves into the womb. It then detects the bounced-back echoes and forms an image. These scans are used during pregnancy to check the baby is developing normally.

STATS AND FACTS

TIMELINE OF DEVELOPING UNBORN CHILD

EYES	20 days
HEART	22 days
LEGS	28 days
NOSE	35 days

21 weeks The time the fetus takes to grow to the size and weight of a banana

5,000 CELLS PER SEC ADDED AT MOST RAPID GROWTH

Time for a rest

Birth is a tiring event. New babies spend around 17 hours of the day sleeping, but they are already learning about the world around them. Life is full of strange and exciting sights, sounds, smells, and sensations.

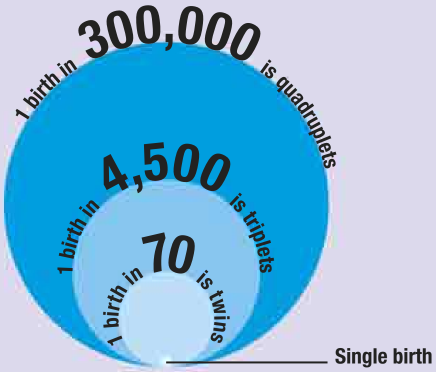
NEW KIDS ON THE BLOCK

Multiple births

Multiple births are two or more babies born from the same pregnancy. For identical twins, one fertilized egg divides into two cells, and then each develops into a baby. For identical triplets, one of these divided cells splits again and each develops into a baby, and so on. These babies have the same genes and so are either all girls or all boys. Non-identical twins happen when two separate fertilized eggs develop into babies. For non-identical triplets, there are three fertilized eggs, and so on.

STATS AND FACTS

CHANCES OF MULTIPLE BIRTHS



PREGNANCY PERIOD

40 WEEKS
NORMAL BIRTH

36 WEEKS
TWIN BIRTH

“The **largest** ever multiple birth babies to **survive** were **octuplets**, born in 2009 in the USA”

GROWING UP

The early years

Can you remember being a new baby? You did little more than sleep, feed, and of course cry when hungry, uncomfortable, or frightened. But you could also look, listen, smell, and feel – and during those early years, you learned faster than at almost any other time. Starting to walk seemed so difficult and you probably fell over dozens of times. This was partly because you were "top heavy" – your head was very large compared with your body. After that there was no stopping you from growing and learning new skills at an incredible rate every day.

"From 18 months a child understands 10 or more new words every day"

THE FIRST TEN YEARS

Each baby is an individual and develops at his or her own rate in size, physical skills, learning, and other abilities. Many youngsters may be slightly ahead or behind the average ages shown here, but nearly all catch up eventually.

0–1 YEARS

When babies first arrive they have little control over anything their body does. Within months they have learned to reach for objects, move about, and communicate basic needs.

- **PHYSICAL SKILLS** Sits up, rolls over, crawls, stands, holds out arms
- **MANUAL SKILLS** Grasps objects, plays with feet and hands
- **MENTAL AND SOCIAL SKILLS** Responds with smiles and squeals, makes babbling sounds

1–2 YEARS

This is the main period for learning to talk and walk. The hand and fingers gradually come under more accurate control to produce a variety of different grasps and grips.

- **PHYSICAL SKILLS** Walks, jogs, runs, kicks ball, throws ball
- **MANUAL SKILLS** Scribbles, picks up small objects, drinks from a cup
- **MENTAL AND SOCIAL SKILLS** Learns single words, understands short sentences

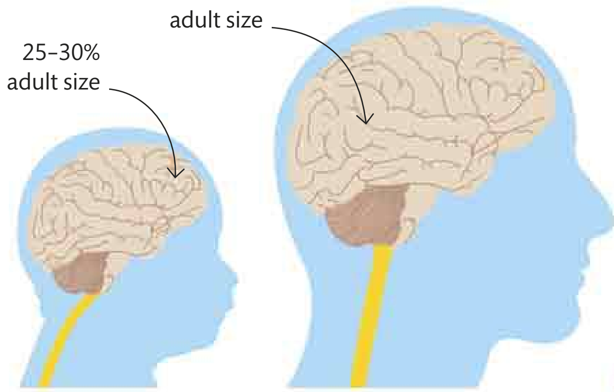
2–3 YEARS

Better hand–eye coordination makes catching and throwing easier. Words are made into simple sentences – toddlers can now take part in conversations and understand instructions.

- **PHYSICAL SKILLS** Balances on one foot, twirls around, pedals a tricycle
- **MANUAL SKILLS** Draws straight lines, places shaped objects correctly, builds brick towers
- **MENTAL AND SOCIAL SKILLS** Knows names; talks in simple sentences, understands more

BRAIN BOOST

One of the most rapid spurts of growth occurs in the brain. At birth it is only 30 per cent of adult size, but has all the neurons it needs. It shoots up in size to 80 per cent by age three, and almost adult size at 12 years. Much of this increase is due to the nerve cells making millions of new connections every day as the child learns new skills.



A CHILD'S BRAIN MAKES 700 NEW NERVE LINKS A SECOND

Children need 10–12 hours of sleep to grow

3–6 YEARS

"Self-centred" problems, such as temper tantrums, come under control as children start mixing with others at playgroup and school. Also, they make progress in writing and drawing.

- **PHYSICAL SKILLS** Catches ball, skips, hops on a leg
- **MANUAL SKILLS** Draws people, animals, and objects; copies shapes and matches colours; writes names, dresses without help
- **MENTAL AND SOCIAL SKILLS** Understands sharing, relates to helping others

6–10 YEARS

At this age, physical development and skill levels improve rapidly with practice. A growing self-awareness makes youngsters realize they are individuals as well as part of various social groups.

- **PHYSICAL SKILLS** Plays sport, develops fine motor skills
- **MENTAL SKILLS** Develops self-control, thinks independently, begins to question others
- **SOCIAL SKILLS** Develops close friendships, seeks privacy, appreciates need to control strong feelings

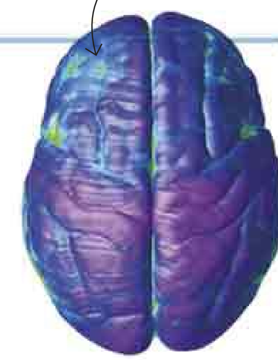
TEEN TIME

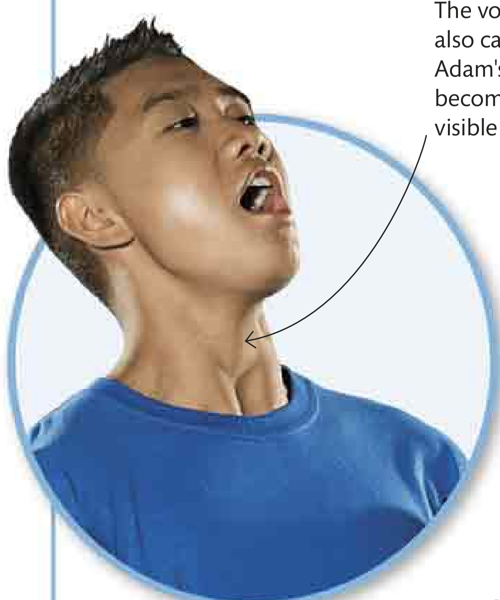
Reaching puberty

The teenage years, ages 13 to 19 – and just before them – are times of enormous change. Under the control of hormones, a child's body grows into that of an adult. It goes through a big growth spurt, changing shape and proportions. Younger girls and boys have much the same overall body outlines, but these change as outward features develop differently for women and men. Hormones also bring transformations within the body, as the reproductive parts begin to work. This time is called puberty.

REWIRING

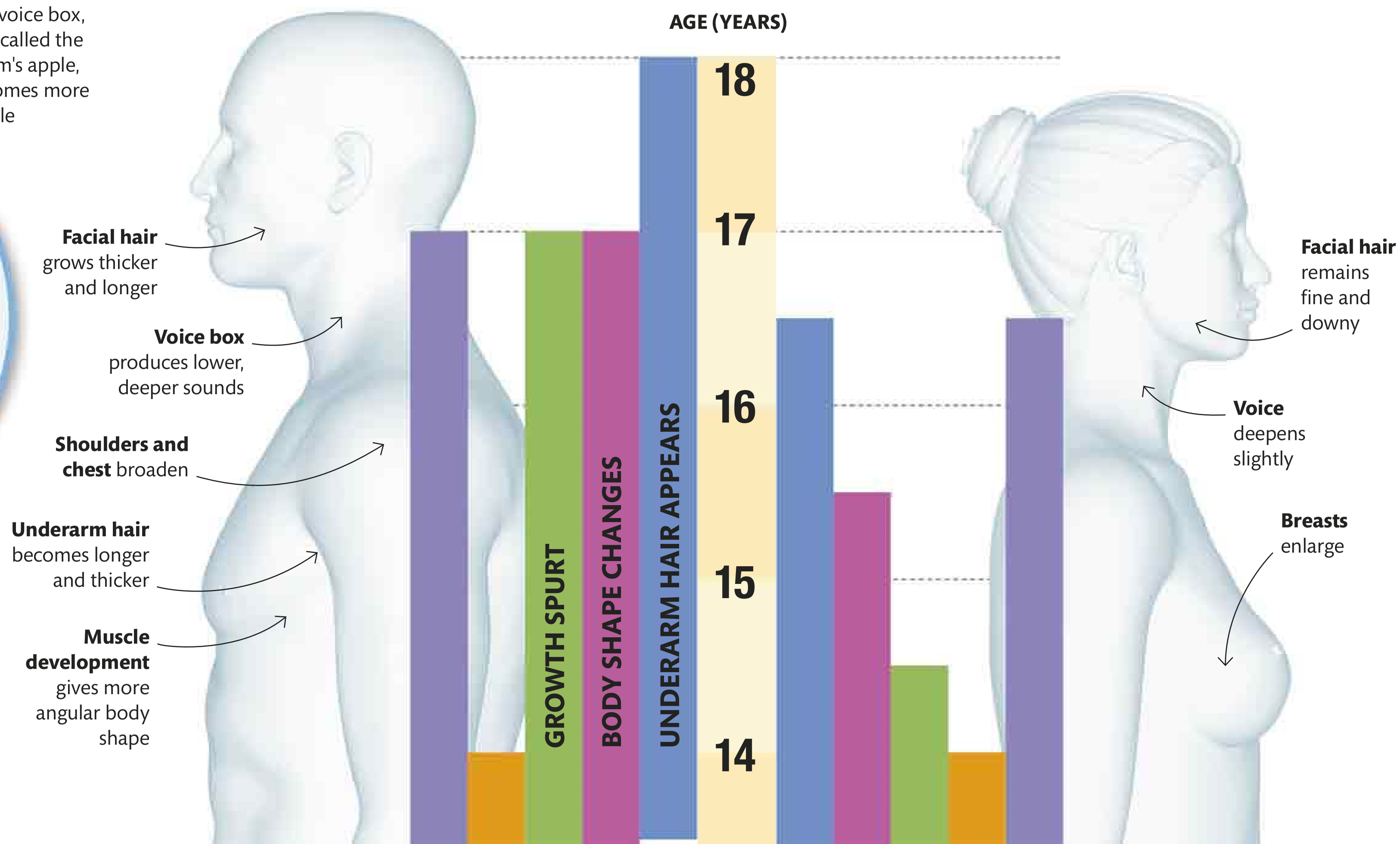
Teenage brains undergo drastic rewiring during puberty. Connections between different areas are broken and remade as part of the process of making you more independent. However, it can make life seem tricky until everything settles down.



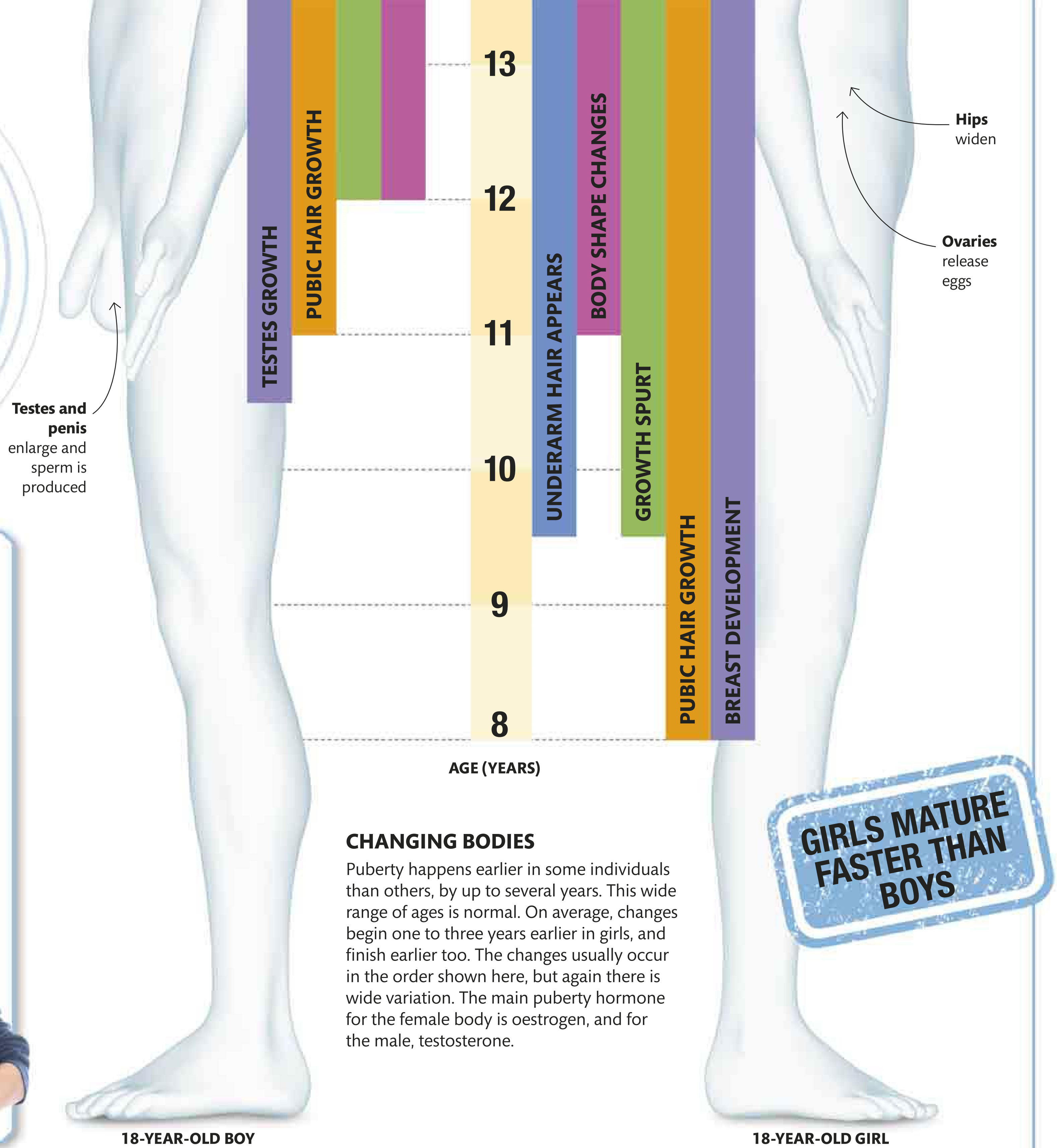


VOCAL CHANGES

As the body matures, the vocal cords in the voice box become thicker and longer. This happens more noticeably in males, causing the cords to vibrate more slowly, giving a deeper voice.



> **"By the end of puberty boys have about 1.5 times as much muscle as girls"**



GROWTH SPURT

Girls and boys have similar heights from birth. While girls usually start their growth spurt earlier, often making them taller than boys the same age, in boys it is faster and more obvious. By adulthood, men are usually taller than women.

CHANGING BODIES

Puberty happens earlier in some individuals than others, by up to several years. This wide range of ages is normal. On average, changes begin one to three years earlier in girls, and finish earlier too. The changes usually occur in the order shown here, but again there is wide variation. The main puberty hormone for the female body is oestrogen, and for the male, testosterone.

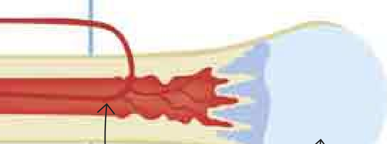
PHYSICAL PROGRESS

Growth and change

All living things, including humans, pass through a series of life changes. The body reaches maximum size, strength, and coordination at around 20–30 years of age. These features begin to fade from about 40–45 years of age, very slowly at first. But the brain continues to gather experience with memories and knowledge that can help wise thinking and decision-making.

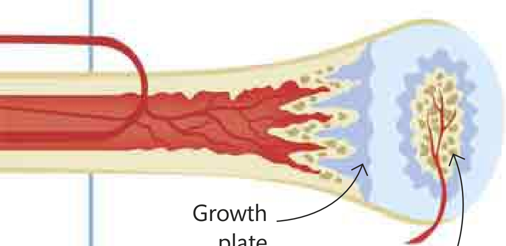
BONE GROWTH

When the baby is still in the womb, bones first form as structures of cartilage. These harden into true bone tissue over the years. Height mainly increases by the leg bones lengthening at sites called growth plates.



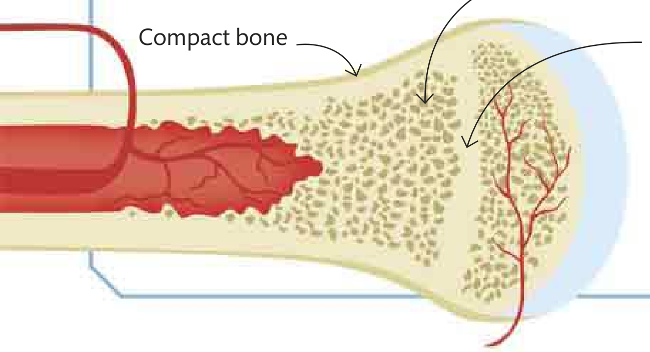
Early bone

In a newborn baby, the shaft of the bone has hardened into bony tissue while other parts are still mostly cartilage.



Growing bone

In childhood, bones lengthen as cartilage from the growth plate and secondary growth site hardens into bone.

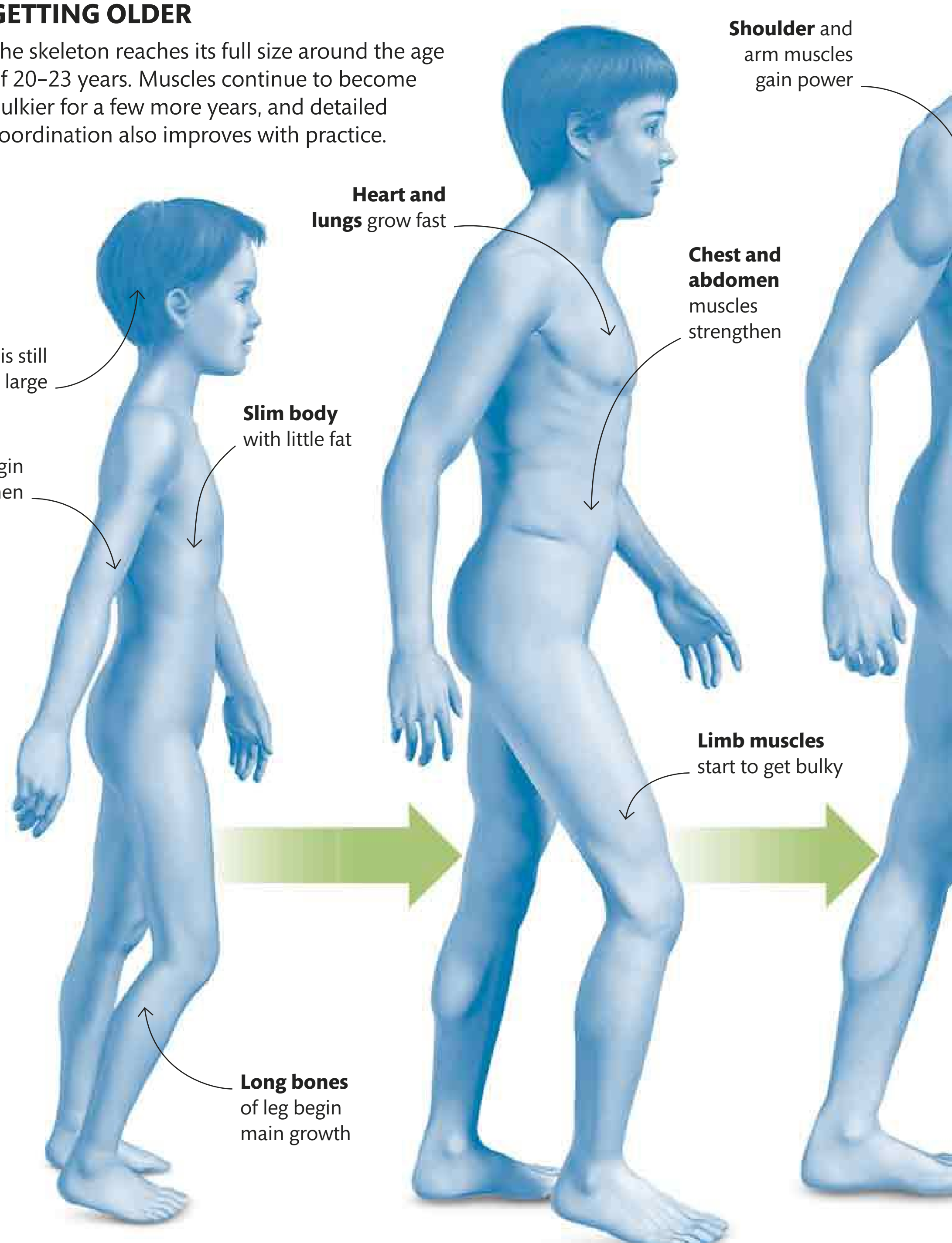


Mature bone

Lengthening of the bone slows and stops by the late teens. Almost all cartilage has hardened into continuous bone.

GETTING OLDER

The skeleton reaches its full size around the age of 20–23 years. Muscles continue to become bulkier for a few more years, and detailed coordination also improves with practice.



10 years

Rate of height increase peaks for girls, and a year or two later for boys. This is due mainly to growth of the long bones in the legs – the femur in the thigh, and the tibia and fibula in the lower leg.

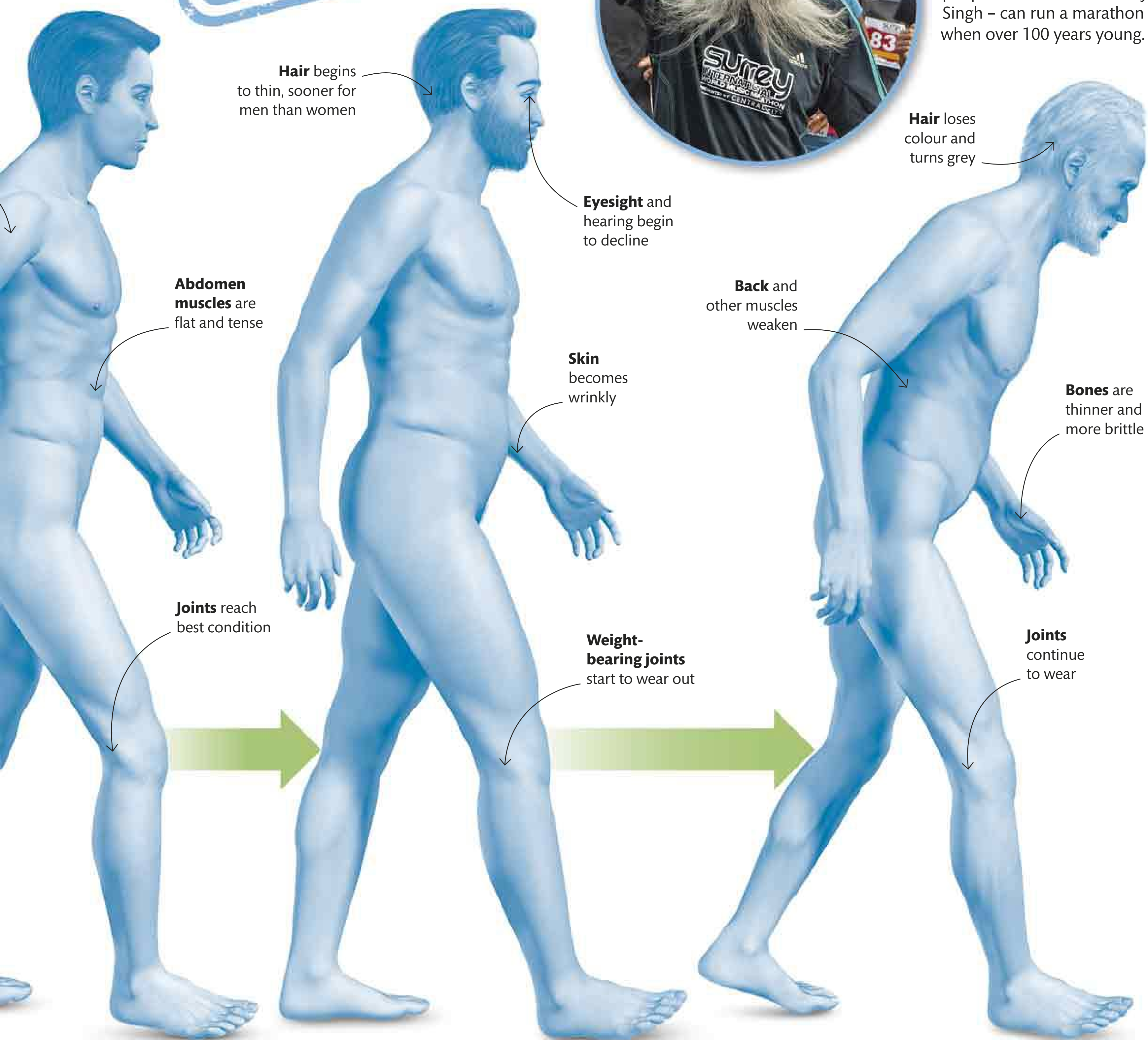
17 years

Most girls reach their full height and changes of puberty are almost complete. About half of boys are still finishing their growing spurt. Muscle development is 80 per cent complete.

ALL MUSCLE FIBRES ARE PRESENT FROM BIRTH

KEEP ON RUNNING

As with the entire life cycle, the rate of ageing is different in different people. Keeping the body and mind active, helped by the right long-living genes, some people – such as Briton Fauja Singh – can run a marathon race when over 100 years young.



25 years

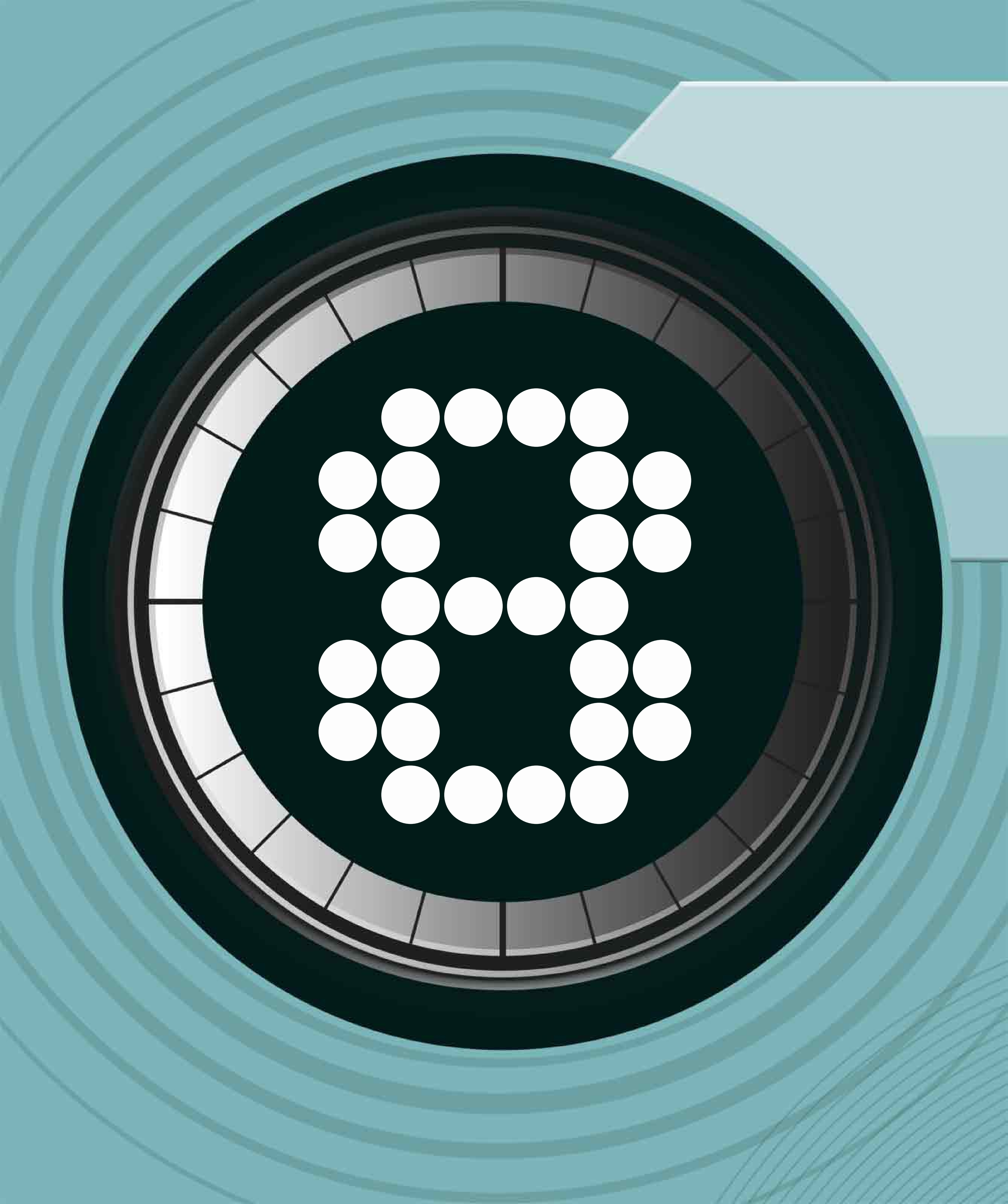
The average body is at its greatest height and maximum upright posture. Muscles are ready for their fullest development, although this depends hugely on the amount of physical exercise and training.

60 years

Some joints begin to stiffen, skin loses its stretchiness, and there is a slight height loss. With reduced activity, fat gathers more easily. Senses gradually become less keen and reactions slower.

80 years

Muscles gradually lose their power. The backbones and the cartilage discs between them slowly shrink, so the body may stoop forward. Senses diminish, and brain power and memories lessen.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FUTURE HUMANS

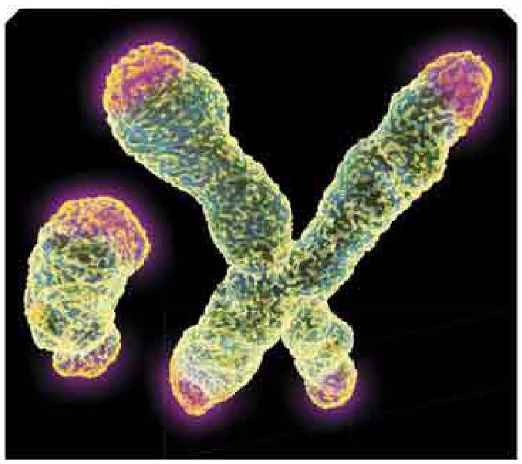
Humans could change far more in the next 100 years than they have in the last 200,000 years. Computer technology, robotics, genetic engineering, and biotechnology are the forces driving a very different kind of human "evolution" – and powering us into the future.

STAYING ALIVE

Increasing longevity

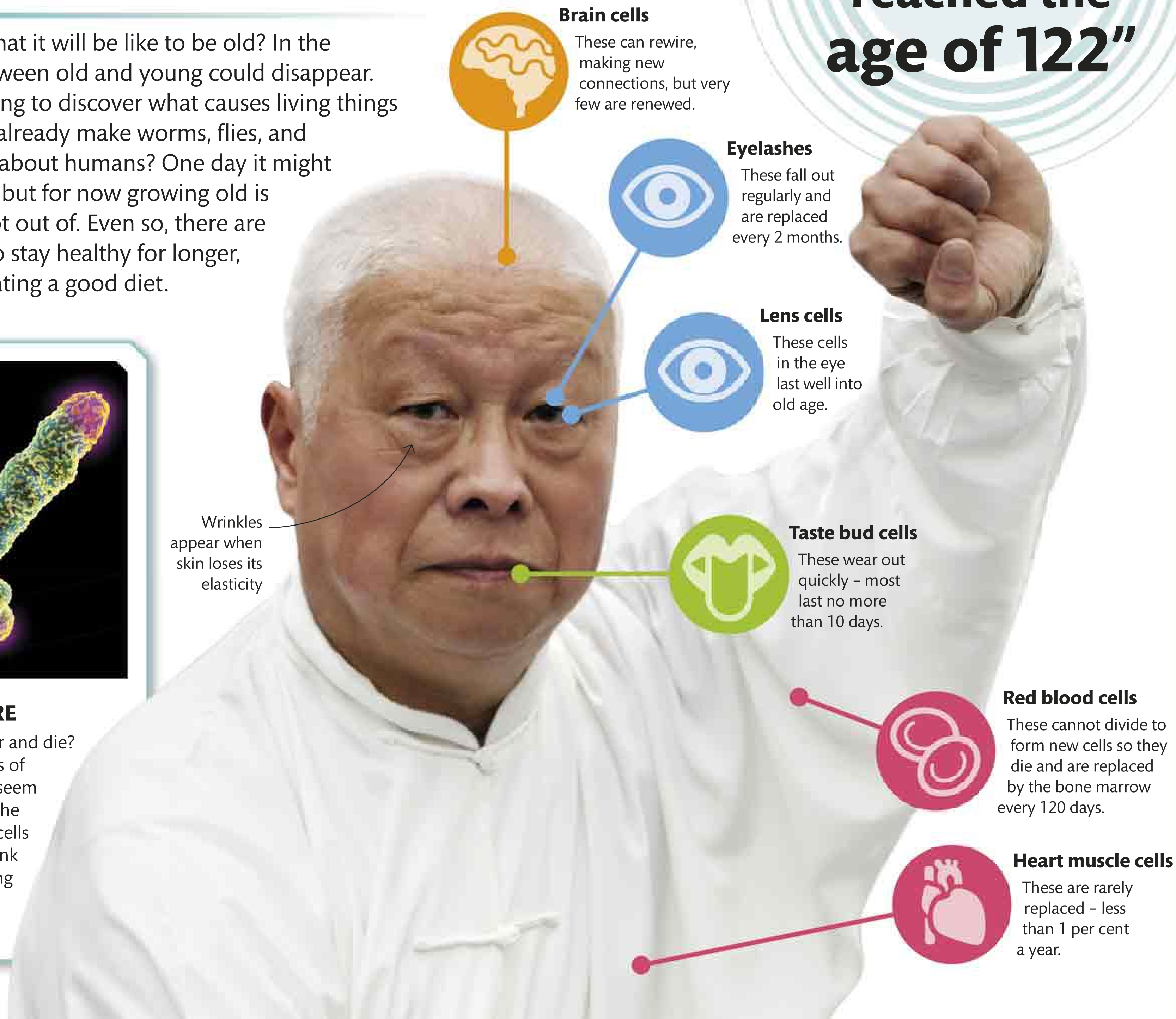
"The oldest person on record, Jeanne Calment, reached the age of 122"

Do you ever imagine what it will be like to be old? In the future, the difference between old and young could disappear. Scientists are slowly starting to discover what causes living things to age and die. They can already make worms, flies, and mice live longer, so what about humans? One day it might be possible to halt aging, but for now growing old is not something we can opt out of. Even so, there are many things we can do to stay healthy for longer, such as keeping fit and eating a good diet.



SHRINKING THE FUTURE

Why do our bodies grow older and die? Telomeres (the protective ends of chromosomes, shown in red) seem to play a part. As cells divide, the telomeres shrink, making the cells more vulnerable. Scientists think exercise might slow down aging by producing a chemical that helps telomeres last longer.

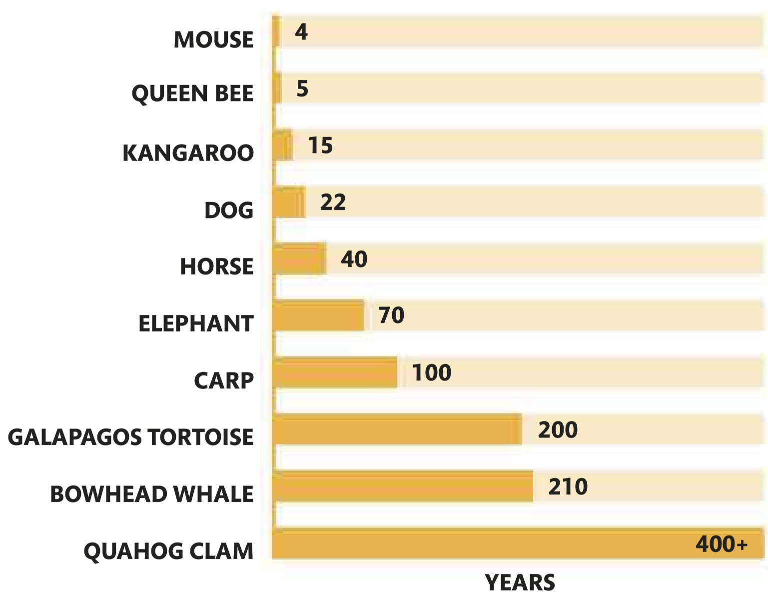


YOUNG AT HEART

On average, people in developed countries now live 5–10 years longer than they did in the 1970s. That means there are many more older people in the world than there used to be. By 2020, there will be over a billion people aged over 60, and 70 per cent more elderly people in the world than there were in 2000.

HOW WE COMPARE WITH OTHERS

Flies can die within a week, while oak trees might live 1,000 years. Bigger organisms generally live longer than smaller ones. No one knows exactly why, but bigger animals and plants have fewer predators, can store more food, and reproduce when they are older. These things help them live longer.



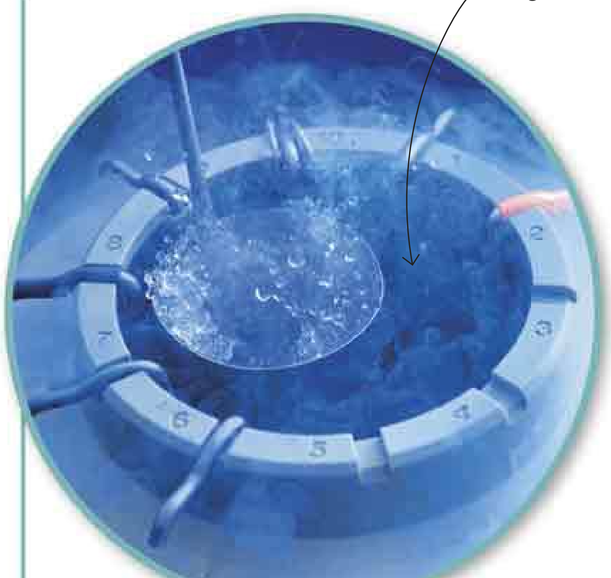
TO BOLDLY GO

Life in space

After millions of years of evolution, humans are perfectly at home on Earth. We are well adapted to living in our water-covered world that spins around the Sun. But what if life on Earth becomes impossible in the future? If a terrible disease threatens humanity, or climate change scorches our planet into a baking desert, the entire human race might have to pack its bags and head for the stars. Could we start afresh in the dark depths of space?

Human body frozen for thawing later

FEWER THAN 550 PEOPLE HAVE GONE TO SPACE



Eggs frozen in liquid nitrogen for storage

LIFE IN SPACE

In space, everyday chores are way out of this world. Even simple shopping trips could mean dodging dust-storms, bursts of sun radiation, and winds colder than Earth's South Pole! What would you drive? Maybe this electric, voice-steered Eurobot – its two arms are great for everything from exploring rough terrain to packing your shopping.

SEED SHIPS

Should Earth become unlivable and we had no place else to go, in an attempt to ensure the continuity of our species we could send seed ships into space. These uncrewed spacecraft carrying human cells or embryos could artificially restart our civilization.

SPACE COLONIES

Water, sunlight, food, and gravity are essential things humans would need in order to survive in space. If we were unable to find another livable planet, we could build a space station. Spinning slowly, like a giant mouse wheel, it would make its own gravity. Vast mirrors could catch sunlight to grow plants for food.

Helmet with built-in communication devices

Biosuit is fitted, light, and flexible

Gloves zip onto suit

SPACE WARDROBE

Today's spacesuits have about 14 layers, including thermal underwear, breathing apparatus, and a toughened outer shell. To live in space forever, we will need simpler space fashions that are much more comfortable.

"437 days is the longest time a person has spent in space at a stretch"

Freeze pod is vacuum sealed

SUSPENDED ANIMATION

It could take hundreds of years to reach a livable planet, but no-one can survive that long. We could freeze people to stop them ageing and thaw them back to life on arrival. But while scientists can freeze sperm for 40 years, they do not know how to freeze and revive humans yet. A method of instantly freezing all the cells in the body is needed, or else it could rot!

Mini machines

75% OF PEOPLE LIVE FOR 5 YEARS AFTER A HEART TRANSPLANT

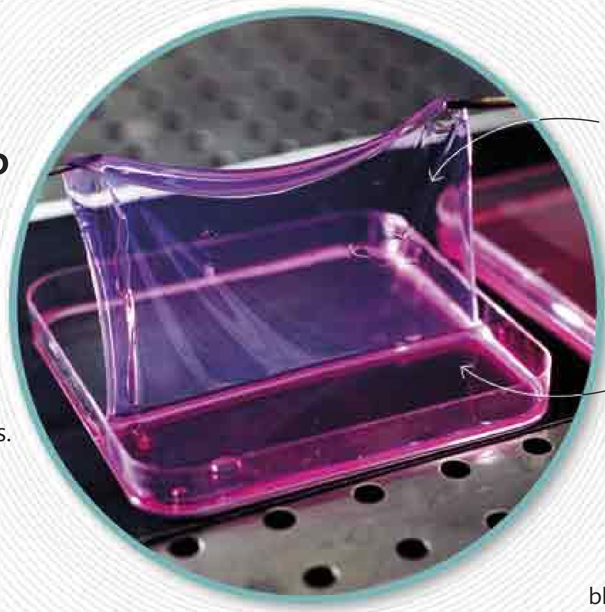
When sickness wages war inside your body, you need help to get well again. Today, we swallow medicines – chemicals that drift through our blood, fighting disease. Tomorrow, our bodies may fight back with help from nanobots – mini surgical robots about the same size as body cells. Engineers can already build micromachines from atoms and molecules. In the future, technological advances may allow them to make robots with microscopic sensors that can pinpoint rogue cells or bacteria and destroy them.

Body building

Nanobots could be preprogrammed to find damaged or diseased parts of your body and repair them. Racing round the motorways of your bloodstream, they might use onboard cameras to identify rogue cells. Some may use miniature robot arms to dismantle germs, atom by atom, while others could pump medicines into diseased cells.

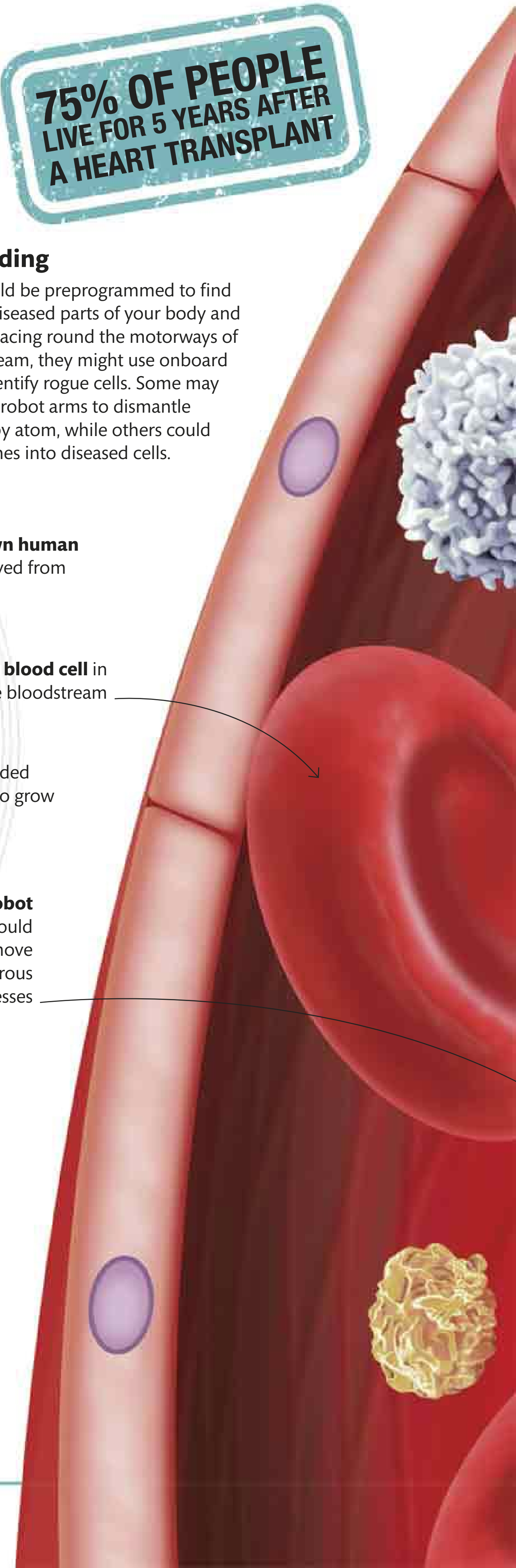
NEW SKIN FOR OLD

Skin usually heals after a cut or burn, but not if the damage is serious. Fortunately, scientists have now developed artificial skin. It takes just three weeks to grow a square metre (11 sq ft) in these special culture dishes.



Artificially grown human skin being removed from a culture dish

Gel contains nutrients needed by skin cells to grow

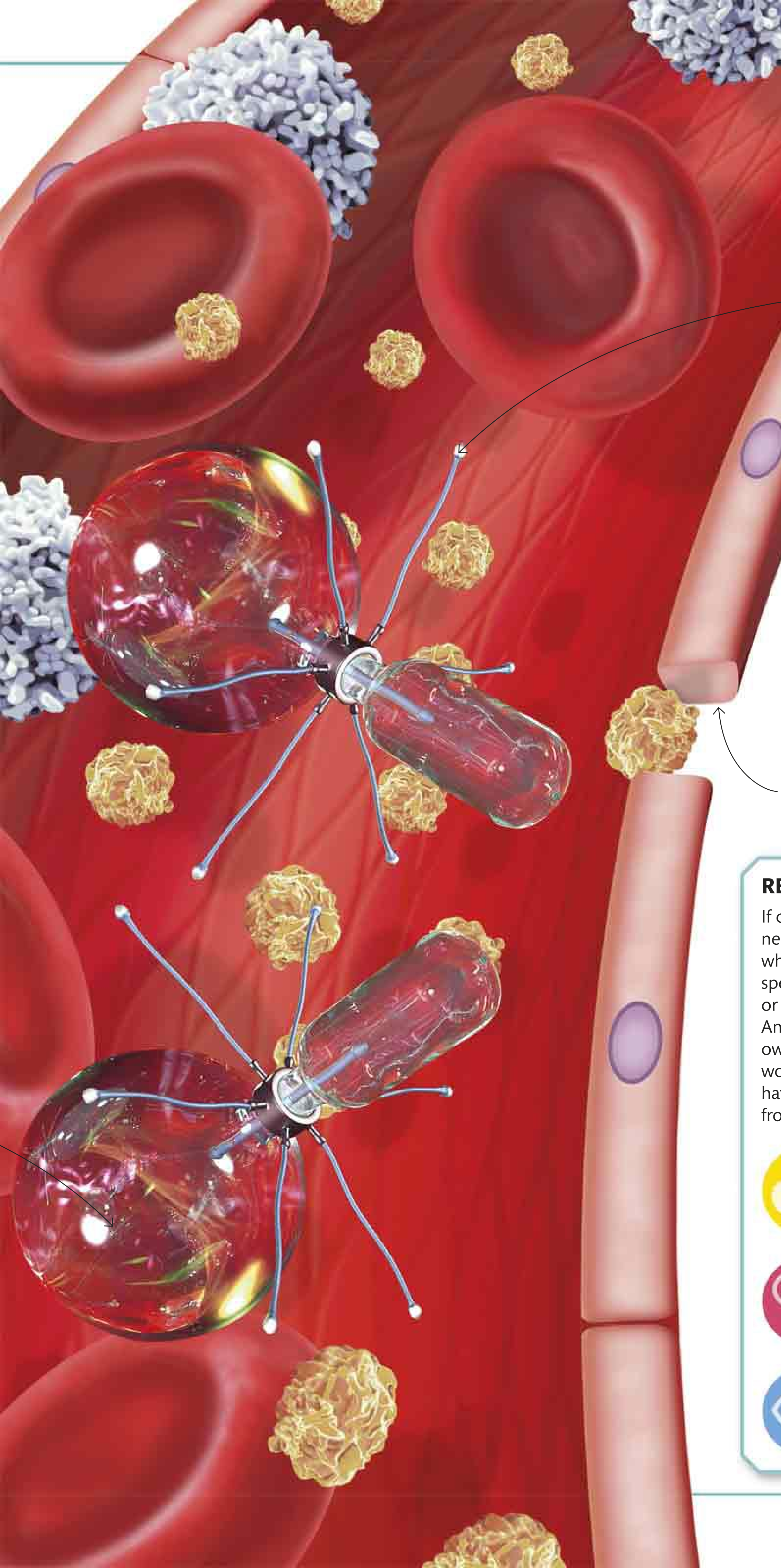


Red blood cell in the bloodstream

Nanobot in blood vessel could detect and remove blockages or cancerous cells, and fight illnesses

3D PRINTING

Inkjet computer printers draw pictures on paper by squirting ink. In a similar way, 3D printers make objects by squirting plastic. They use nozzles that slide back and forth, building up an object in thin layers. Doctors are now using 3D printers to make instant plastic replacements for body parts, such as fingers and ears. In the future, printers could use cells to print organs made of living tissue.



"Nanobots would be about one-tenth the width of a human hair"

REPLACEMENT ORGANS

If one of your body organs is damaged, you might need to replace it. Organs are donated by people who have died or from friends or family. In future, specially bred animals could donate whole organs or cells. This idea is called xenotransplantation. Another possibility would be to use a person's own stem cells to grow replacement tissues. This would get around the problem of the patient having to take drugs to prevent his or her body from attacking the donated organ.

Pancreas cells

These help us make insulin and digest food. Replacements from animals could help cure diabetes.

Red blood cells

These cells could be used to make artificial blood, reducing the need for blood transfusions.

Eye tissues

Instead of transplants, people with damaged corneas, or eye tissues, could have specially grown replacements.

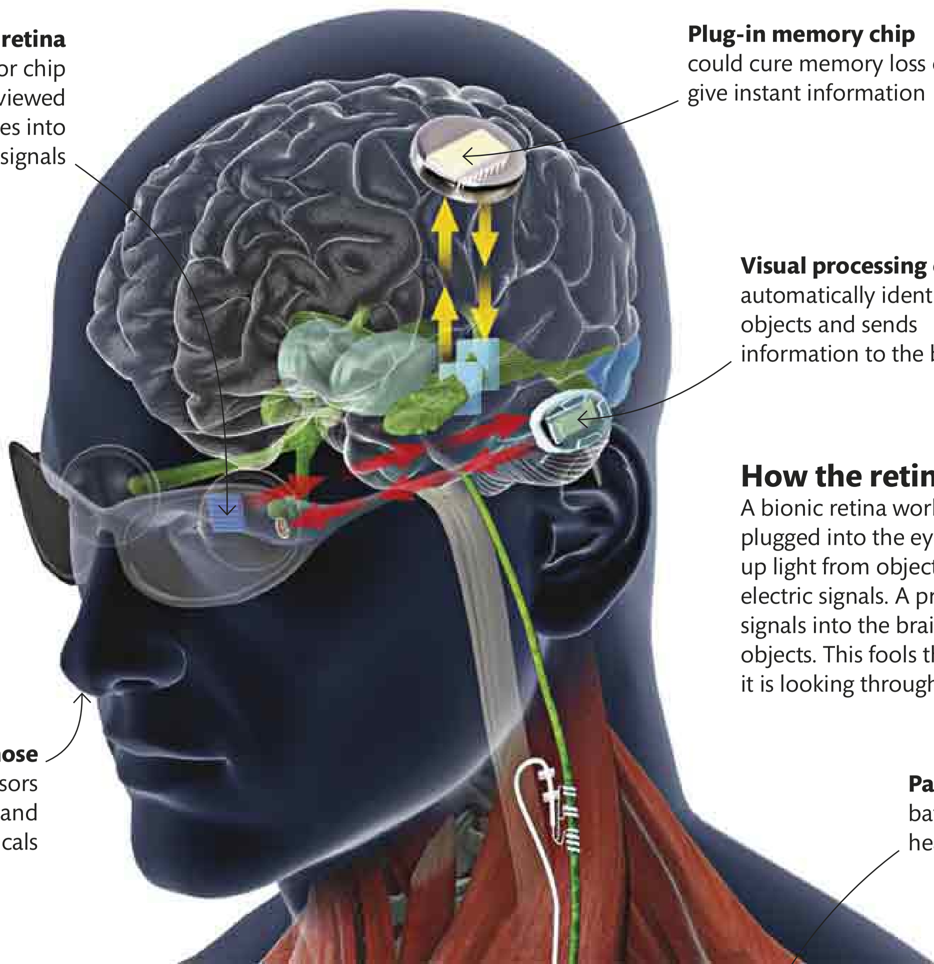
BIONIC BODIES

Rebuilding the body

Would you like zoom lenses for eyes, arms that can lift cars, or legs that could speed you down a track faster than a cheetah? All these things could become quite common within the next 100 years, helping you to stay fit and active. Although our bodies constantly rebuild themselves, they wear out eventually. But as we slowly swap ageing flesh and broken bone for more and more bionic – mechanical and electronic – replacements, a whole world of possibilities opens up for enhancing our bodies beyond their current physical capabilities.

EXOSKELETONS

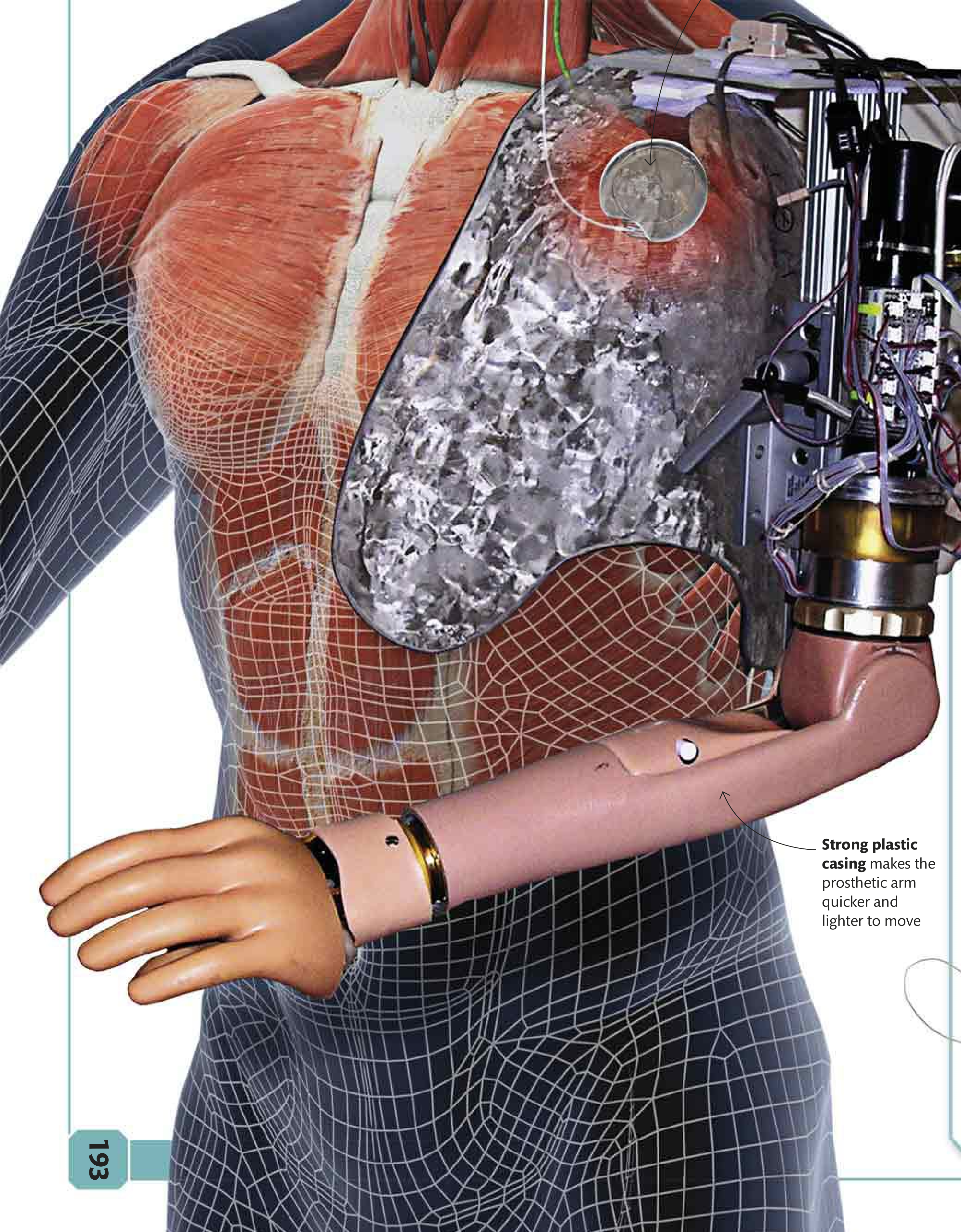
Invented in 1846, artificial legs are a big help for people who have lost limbs. For paralyzed people, exoskeletons are better. Bionic walking assistance systems are designed to help such people walk again using electronic chest-mounted sensors. As you rock from side to side, electric motors, powered by a battery backpack, move your legs using sturdy braces.



How the retina works

A bionic retina works like a digital camera plugged into the eye. A sensor chip picks up light from objects and converts it into electric signals. A processor chip fires the signals into the brain area that recognizes objects. This fools the brain into thinking it is looking through a camera.

"Exoskeletons can make people 25 times stronger"



PART HUMAN, PART ROBOT

Today, you can get spare parts for your car. Tomorrow, you will be able to repair your body with devices like those shown here. One day, it may even be hard to tell the difference between patched-up humans and brand-new robots.

How the arm works

Bionic arms pick up signals from the brain and turn them into movements. Sensors in the upper arm detect the signals, which a computer chip decodes. The chip then fires up electric motors in the arm to make it move.

BIONIC WARDROBE

Bionic bodies might sound like science fiction, but we already have the technology to swap about half the human body with spares. Future developments in materials and technology will make them easier to use and improve the way they work.

Heart pacemaker

The pacemaker sends signals to the heart's muscles to keep them beating regularly.

Running blades

Legs are a third of our body weight. These blades are light and springy, for running.

Cochlear implant

A microphone on the head picks up sounds and sends them directly to the inner ear.

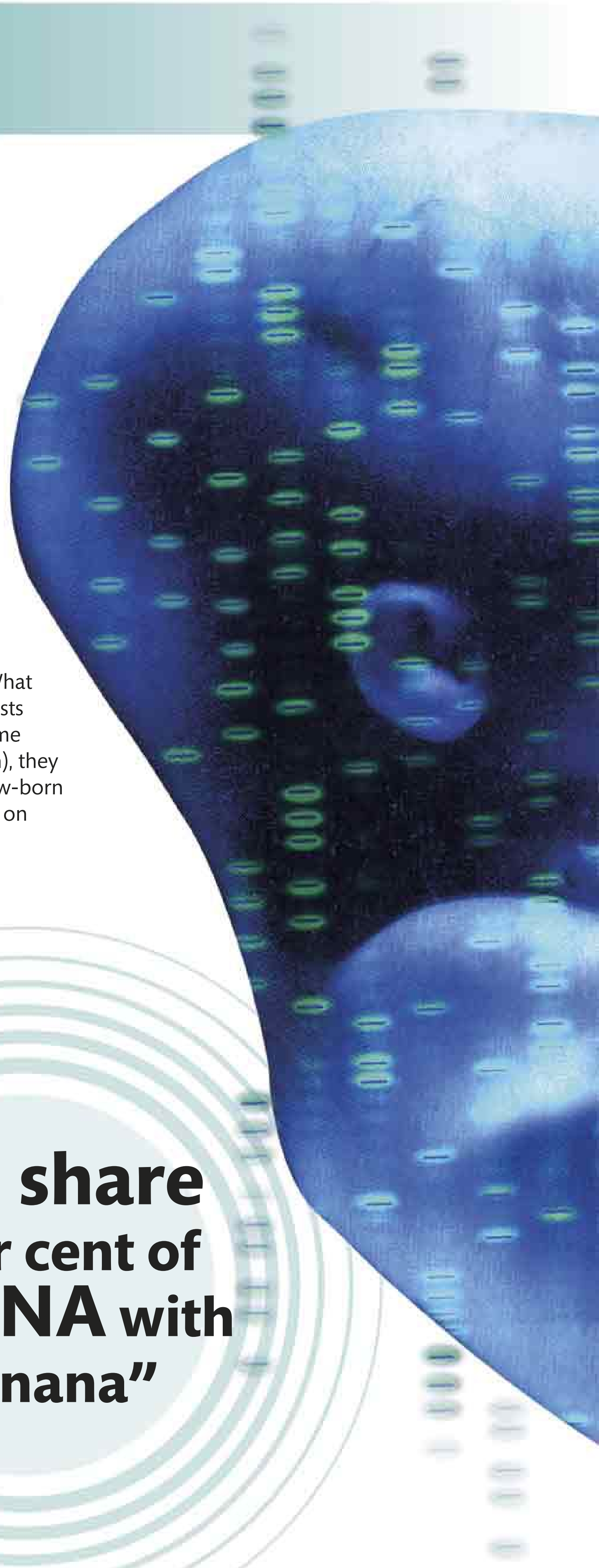
Artificial eye

These plastic eyes resemble real eyes, although they do not help you see.

ALL IN THE GENES

Genetic engineering

Babies aren't crystal balls: you can't look in their eyes and see their future. How we turn out is a mixture of nature (determined by genes) and nurture (received from the world around us). Scientists now know far more about genes and how they control development. That could make it easier to engineer superhumans who will never suffer terrible diseases. But could it open the door to a scary future where perfect "designer" children are churned out like plastic dolls from a factory?



CLONING HAS A 95–99% FAILURE RATE

DESIGNER BABIES

Should parents be able to choose their baby's sex before it's born? What about other features? Once scientists fully understand the human genome (our complete genetic information), they might engineer any aspect of a new-born child as easily as choosing options on a new car. Should humans dare to design life better than nature?

GENE THERAPY

Engineering our genes could bring huge benefits to humanity, such as curing types of cancer. Some illnesses happen when genes in our cells mutate (go wrong and develop harmfully). In gene therapy, cells containing faulty genes are removed from a person's body, the genes are replaced with working ones, and then the cells are injected back again, curing the disease.

"You share 50 per cent of your DNA with a banana"

CLONING

Extract the genetic information from your body and grow it into another person, and you'll get a clone (an identical copy of yourself). In 1996, scientists cloned a sheep called Dolly. In future, cloning could make identical babies or mass-produce farm animals for food. Or it could make stem cells, general-purpose body-repair cells that could help cure illnesses such as heart disease, Parkinson's, and diabetes.

CHOOSING CHARACTERISTICS

As a future parent, you might design your baby from a menu. Doctors could give you a list of options from which you pick the ones you prefer. Many would think this wrong, but who knows how far we would go down the route of picking our "perfect child".

EYES

You could choose your baby's eye colour. Cloning could also help avoid genetic eye disorders and some kinds of blindness.

HAIR

Babies could be designed with a certain hair colour, with straight or curly hair, and natural resistance to baldness in later life.

INTELLIGENCE

It might not be possible to clone smarter children. Scientists believe how we are raised is just as important as genetic factors.

HEIGHT

Plants have long been selectively bred to make them taller or shorter. Future babies might be engineered the same way.

SEX

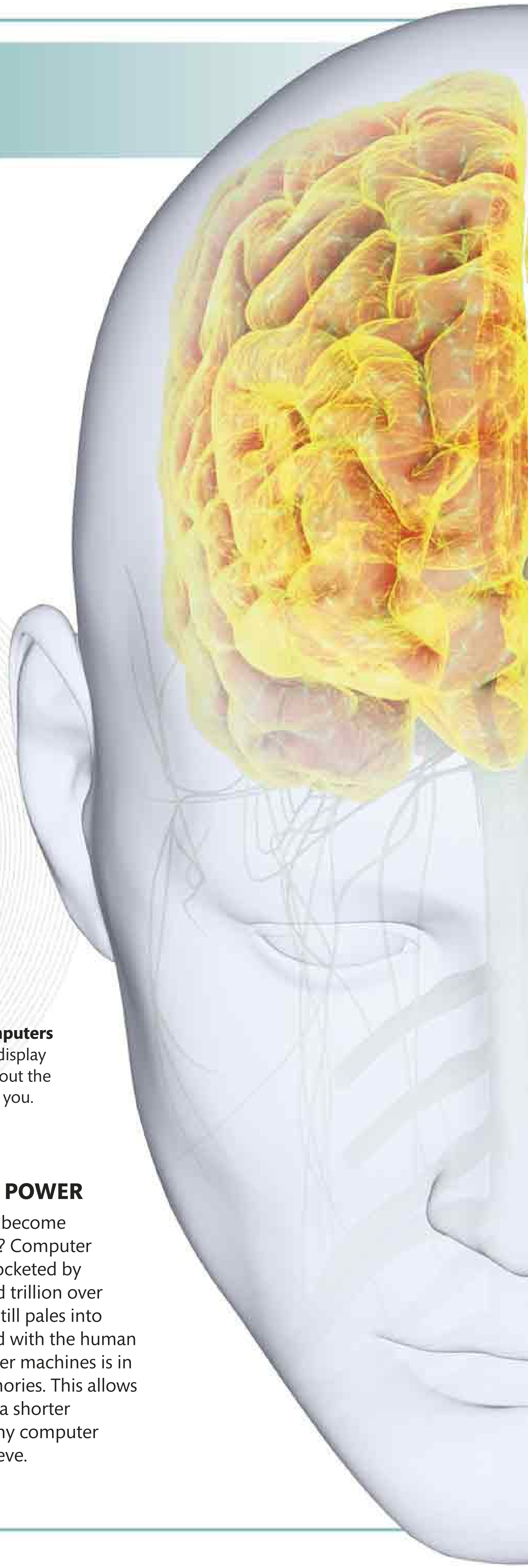
In some countries, male babies are still valued more. If too many parents choose boys, what will happen to the human race?

ABILITIES

A strong child could grow into an Olympic champion, but most human abilities do not depend on our bodies in such a simple way.

BRAIN GAINS

The future brain

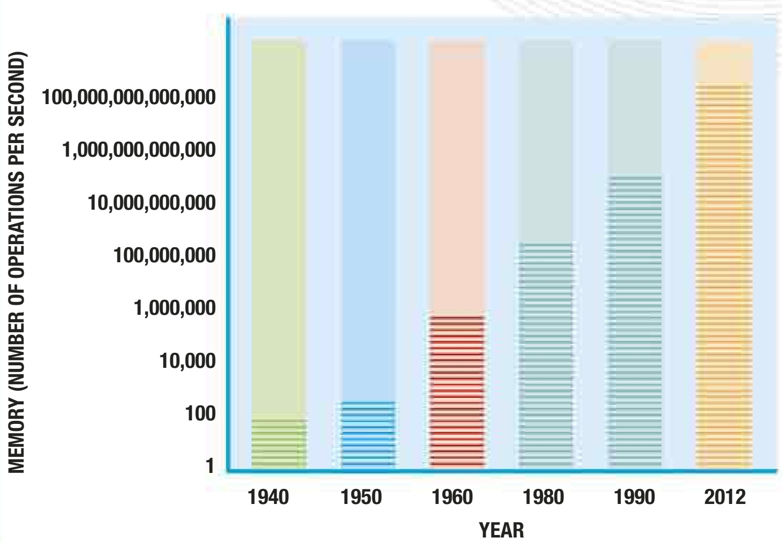


Everything you've ever learned, everything that's ever happened to you, and everything you know about everyone you've ever met is packed into a lump of mush the size of a pudding bowl balanced on top of your head – your brain. Humans have managed perfectly well with the way our brains work for several million years, but the development of powerful computers, over the last 50 years or so, has given us an amazing new opportunity. Could we blend computer technology with our brains to make ourselves much smarter?

AUGMENTED REALITY

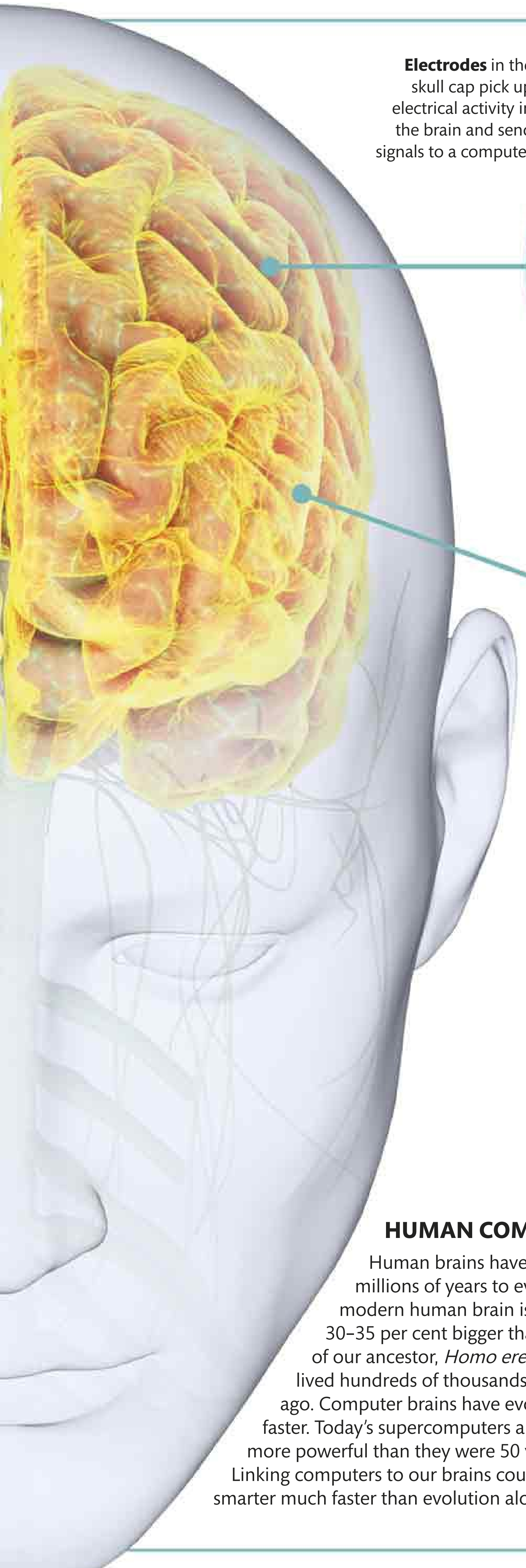
Augmented reality is a way of adding handy information from the Internet to things you can see in front of you. These electronic glasses can draw maps, look up facts, and can project useful information about your surroundings before your eyes. They can also display emails, pinpoint friends who happen to be nearby, and allow you to listen to sound files.

Wearable computers will be able to display information about the objects around you.



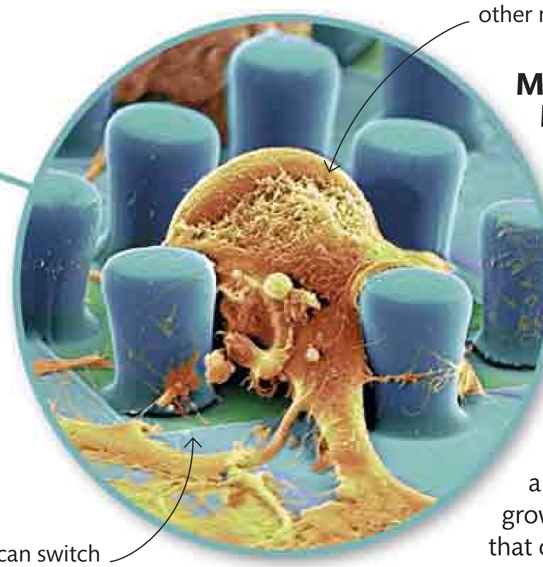
SUPERCOMPUTER POWER

Could the human brain become redundant in the future? Computer processing power has rocketed by a factor of 100 thousand trillion over the last 75 years, but it still pales into insignificance compared with the human brain. Where we win over machines is in our ability to store memories. This allows us to solve problems in a shorter number of steps than any computer running today can achieve.



MIND OVER MATTER

What if we could plug human brains into computers? We could look up interesting facts just by thinking about them or download new languages straight to our memories. It would be good news for paralysed people. They could control wheelchairs, televisions, or household appliances by thought alone.



MERGING WITH MACHINES

Brains are made of neurons (nerve cells), while computers have electronic versions called transistors. If we want to merge brains and computers, we'll need to make neurons talk to transistors. In this experimental computer, a neuron (orange) has been grown on a transistor (green) that can switch it on and off.

HUMAN COMPUTER

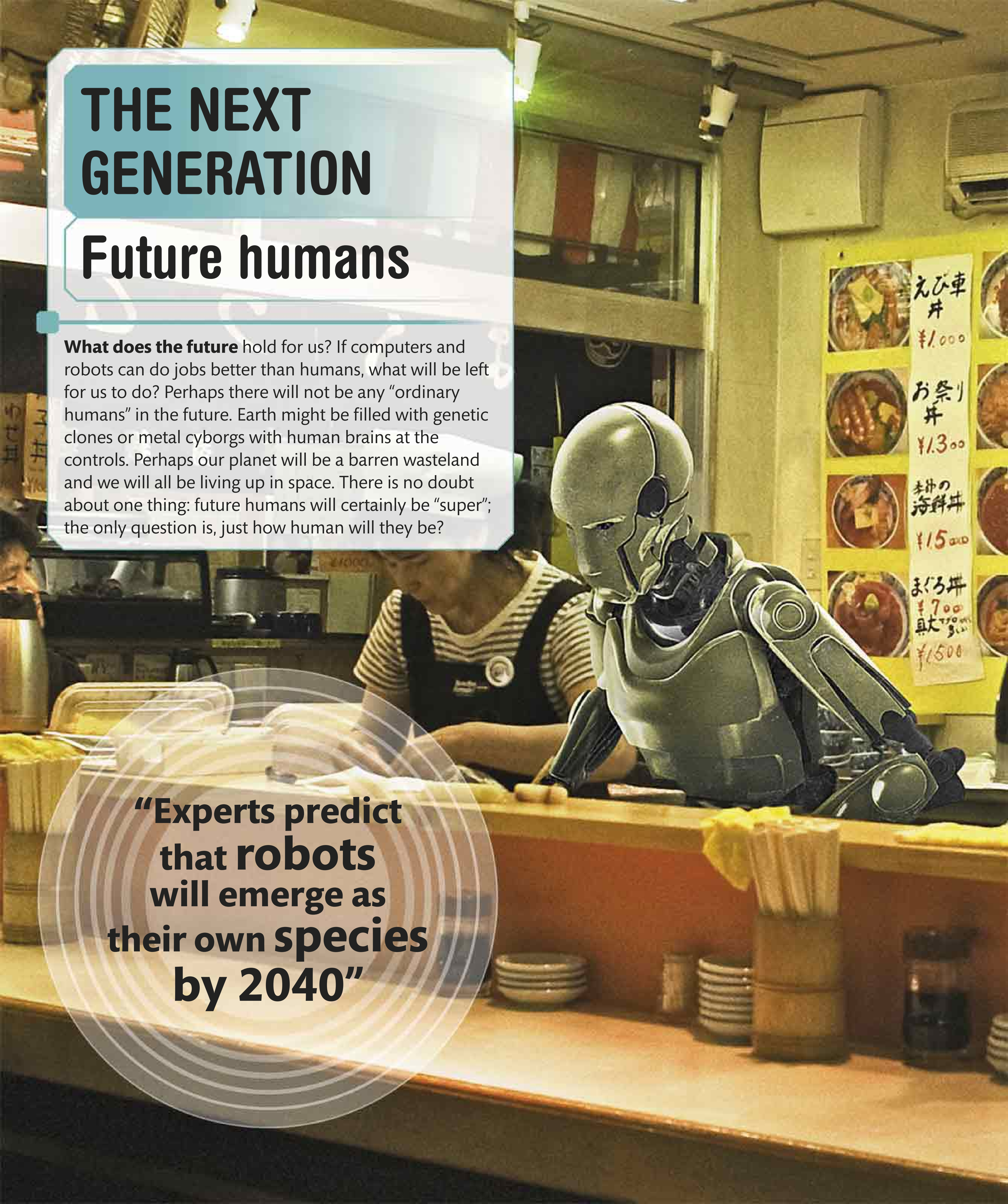
Human brains have taken millions of years to evolve. The modern human brain is about 30–35 per cent bigger than that of our ancestor, *Homo erectus*, who lived hundreds of thousands of years ago. Computer brains have evolved faster. Today's supercomputers are much more powerful than they were 50 years ago. Linking computers to our brains could make us smarter much faster than evolution alone.

"The most powerful computers are only half as powerful as a mouse's brain"

THE NEXT GENERATION

Future humans

What does the future hold for us? If computers and robots can do jobs better than humans, what will be left for us to do? Perhaps there will not be any "ordinary humans" in the future. Earth might be filled with genetic clones or metal cyborgs with human brains at the controls. Perhaps our planet will be a barren wasteland and we will all be living up in space. There is no doubt about one thing: future humans will certainly be "super"; the only question is, just how human will they be?



"Experts predict that robots will emerge as their own species by 2040"

Fiction or future?

If today's technological advancements are anything to go by, a future well beyond fiction awaits us. So, don't be surprised if tomorrow your co-worker, neighbour, or even best friend is a robot.

GLOSSARY

ABDOMEN
The lower part of the main body (the trunk), below your chest.

ABSORPTION
The process by which nutrients from digested food are taken in through the wall of your small intestine and passed into your blood.

ADRENALIN
A hormone that prepares your body for sudden action in times of danger or excitement. Adrenalin is produced by glands on top of the kidneys.

ALLERGY
An illness caused by overreaction of the body's *immune system* to a normally harmless substance.

ANTIBODY
A substance made by the body that sticks to germs and marks them for destruction by white blood cells.

ANTIGEN
A foreign substance, usually found on the surface of germs such as bacteria, which triggers the immune system to respond.

ARTERY
A blood vessel that carries blood away from your heart to your body's tissues and organs.

AUTONOMIC NERVOUS SYSTEM (ANS)
The part of the nervous system that controls unconscious functions such as heart rate and the size of the pupils in your eyes.

AXON
A long fibre that extends from a *nerve cell (neuron)*. It carries electrical signals away from the cell.

BACTERIUM (PLURAL BACTERIA)
A type of microorganism. Bacteria live everywhere. Some types cause disease in humans, but some are beneficial and help to keep your body functioning properly.

BLOOD
A liquid tissue containing several types of cell. Blood carries oxygen, salts, nutrients, minerals, and hormones around your body. It also collects waste for disposal, such as carbon dioxide that is breathed out by your lungs.

BLOOD VESSEL
Any tube that carries blood through your body.

BONE
A strong, hard body part made chiefly of calcium minerals. There are 206 bones in an adult skeleton.

BRAIN STEM
The part of the base of your brain that connects to your *spinal cord*. This controls functions such as breathing and heart rate.

CALCIUM
A mineral used by your body to build bones and teeth. Calcium also helps muscles to move.

CAPILLARY
The smallest type of blood vessel. Your body contains thousands of kilometres of capillaries.

CARBOHYDRATE
A food group that includes sugars and starches, which provide your body's main energy supply.

CARTILAGE
A tough, flexible type of connective tissue that helps support your body and covers the ends of bones in joints.

CELL
The smallest living unit of your body.

CENTRAL NERVOUS SYSTEM
Your brain and spinal cord together make up your central nervous system. It is one of the two main parts of the nervous system.

CEREBELLUM
A small, cauliflower-shaped structure at the base of the back of your brain that helps to coordinate body movements and balance.

CEREBRAL CORTEX
The deeply folded, outer layer of your brain. It is used for thinking, memory, movement, language, attention, and processing sensory information.

CEREBRAL HEMISPHERE
One of the two symmetrical halves into which the main part of your brain (the *cerebrum*) is split.

CEREBRUM
The largest part of the brain, which is involved in conscious thought, feelings, and movement.

CHROMOSOME
One of 46 thread-like packages of deoxyribonucleic acid (DNA) found in the nucleus of body cells.

CONCEPTION
The time between fertilization of an egg cell by a sperm and settling of an embryo in the lining of the womb.

DENDRITE
A short fibre that extends from a *nerve cell (neuron)*. It carries incoming electrical signals from other nerve cells.

DNA
A long molecule found inside the nucleus of body cells. DNA contains coded instructions that control how cells work and how your body grows and develops.

DIGESTION
The process that breaks down food into tiny particles that your body can absorb and use.

DIGESTIVE ENZYME
A substance that speeds up the breakdown of food molecules.

ENDOCRINE GLAND
A type of gland, such as the pituitary gland, that releases *hormones* into your bloodstream.

ENZYME
A substance that speeds up a particular chemical reaction in the body.

EPIGLOTTIS
A flap of tissue that closes your windpipe when you swallow food to stop you choking.

FAECES
Another name for poo – semi-solid waste made up of undigested food, dead cells, and bacteria that are left after digestion and eliminated from your anus.

FAT
A substance found in many foods that provides energy and important ingredients for cells. The layer of cells just under the skin is full of fat.

FERTILIZATION
The joining of a female egg (ovum) and male sperm to make a new individual.

GENES
Instructions that control the way your body develops and works. Genes are passed on from parents to their children.

GENOME
The DNA contained in a set of *chromosomes*. Humans have 46 chromosomes.

GERM
A tiny living thing that can get into your body and make you ill. Bacteria and viruses are types of germ.

GLAND
A group of specialized cells that make and release a particular substance, such as an enzyme or a hormone.

GLUCOSE
A simple type of sugar that circulates in the bloodstream and is the main energy source for the body's cells.

GREY MATTER
Brain tissue that consists largely of the cell bodies of neurons. The outer layer of the brain is grey matter.

HAEMOGLOBIN
A substance in red blood cells that carries oxygen around the body.

HERTZ
A unit used to measure frequency of sound waves. The higher the frequency, the higher the pitch of the sound.

HIPPOCAMPUS
A part of the brain that helps us lay down long-term memories.

HORMONE
A chemical produced by *glands* in order to change the way a different part of the body works. Hormones are carried by the blood.

HYPOTHALAMUS
A small structure in the base of your brain that controls many body activities, including temperature and thirst.

IMMUNE SYSTEM
A collection of cells and tissues that protect the body from disease by searching out and destroying germs and cancer cells.

INFECTION
If germs invade your body and begin to multiply, they cause an infection. Some diseases are caused by infections.

JOINT
A connection between two bones. The knee is the biggest joint in the human body. The bones are usually connected by ligaments.

KERATIN
A tough, waterproof protein found in hair, nails, and the upper layer of your skin.

KILOHERTZ
See hertz

LIGAMENT
A tough band of tissue that connects bones where they meet at joints.

LIMBIC SYSTEM
A cluster of structures found inside your brain that are vital in creating emotions, memory, and the sense of smell.

LYMPHATIC SYSTEM
A network of vessels that collect fluid from body tissues and filter it for germs, before returning the fluid to the bloodstream.

LYMPHOCYTE
A white blood cell specialized to attack a specific kind of germ. Some lymphocytes make antibodies.

MACROPHAGE
A white blood cell that swallows and destroys germs such as bacteria, cancer cells, or debris in damaged tissue.

MELANIN
A brown-black pigment that is found in your skin, hair, and eyes and gives them their colour.

METABOLISM
A term used to describe all the chemical reactions going on inside your body, especially within cells.

MINERAL
A naturally occurring solid chemical, such as salt, calcium, or iron, that you need to eat to stay healthy.

MITOCHONDRION (PLURAL MITOCHONDRIA)
A tiny structure found inside cells that releases energy from sugar.

MOLECULE
A single particle of a particular chemical compound. A molecule is a cluster of atoms – the smallest particles of an element – bonded together permanently.

MOTOR NEURON
A type of nerve cell that carries nerve impulses from your central nervous system to your muscles.

MUCUS
A slippery liquid found on the inside of your nose, throat, and intestines.

MUSCLE
A body part that contracts (gets shorter) to move your bones or internal organs.

MUSCLE FIBRE
A muscle cell.

NERVE CELL
See neuron.

NERVE IMPULSE
A tiny electrical signal that is transmitted along a nerve cell (*neuron*) at high speed.

NEURON
Another word for a nerve cell. Neurons carry information around your body as electrical signals.

NUCLEUS
The control centre of a cell. It contains DNA-carrying chromosomes.

NUTRIENTS
The basic chemicals that make up food. Your body uses nutrients for fuel, growth, and repair.

ORGAN
A group of tissues that form a body part designed for a specific job. Your heart is an organ.

OSTEON
Tubular structures that make up compact bone. Also known as Haversian system.

OVUM
Also called an egg, this is the female sex cell, which is produced by, and released from, a woman's ovary.

OXYGEN
A gas, found in air, that is vital for life. Oxygen is breathed in, absorbed by the blood, and used by cells to release energy from glucose (a simple sugar).

PERISTALSIS
The wave of muscular squeezes (contractions) in the wall of a hollow organ that, for example, pushes food down the oesophagus during swallowing.

PROTEINS
Vital nutrients that help your body build new cells. Foods such as meat, eggs, fish, and cheese are rich in proteins.

PROTIST
A single cell organism – some cause diseases in humans.

ABBREVIATIONS USED IN THIS BOOK

/	per – for example, km/h means kilometres per hour
°C	degrees Centigrade
Cal	calories (equal to 1kcal)
cm	centimetre
dB	decibel
°F	degrees Fahrenheit
fl oz	fluid ounce
ft	foot
g	gram or gravity
Hz	hertz – see glossary for definition
in	inch
kg	kilogram
kHz	kilohertz – equal to 1,000 Hz
km	kilometre
lb	pound
m	metre
min	minute
ml	millilitre
mm	millimetre
mph	miles per hour
oz	ounce
s or sec	second
sq	square

RED BLOOD CELL
A disc-shaped cell that contains haemoglobin (a protein that carries oxygen and makes your blood red).

REFLEX
A rapid, automatic reaction that is out of your control, such as blinking when something moves towards your eyes.

RETINA
A layer of light-sensitive neurons lining the back of each eye. The retina captures images and relays them to the brain as electrical signals.

ROD CELL
A light sensitive cell in the back of the eye. Rods work in dim light but do not detect colour (see also *cones*).

SALIVA
The liquid in your mouth. Saliva helps you taste, swallow, and digest food.

SEBUM
An oily liquid that keeps your hair and skin soft, flexible, and waterproof.

SENSORY NEURON
A type of nerve cell (neuron) that carries impulses from your sense organs to the central nervous system.

SENSORY RECEPTOR
A specialized nerve cell or the end of a sensory neuron that detects a stimulus, such as light, scent, touch, or sound.

SPERM
The male sex cells, which are made in, and released from, a man's testes.

SPHINCTER
A ring of muscle around a passageway or opening that opens and closes to control the flow of material, such as urine or food, through it.

SPINAL CORD
A column of nerve cells (neurons) that runs down your backbone and connects your brain to the rest of your body.

SPINAL NERVE
One of the 31 pairs of nerves that branch out from your spinal cord.

SWEAT
A watery liquid produced by glands in the skin. Sweat cools the body as it evaporates.

SYNAPSE
The junction where two nerve cells (neurons) meet but do not touch.

SYSTEM
A group of organs that work together. Your mouth, stomach, and intestines make up your digestive system.

TENDON
A cord of tough connective tissue that links muscle to bone.

TISSUE
A group of cells that look and act the same. Muscle is a type of tissue.

TOXIN
A poisonous substance released into the body by a disease-causing bacterium.

ULTRASOUND
An imaging technique that uses inaudible, high-frequency sound waves to produce pictures of a developing baby in the womb or of body tissues.

VEIN
A blood vessel that carries blood towards your heart.

VELLUS HAIR
One of the millions of fine, soft hairs that grow all over your body.

VENULE
A small blood vessel (smaller than a vein) that returns blood to the heart.

VIRUS
A kind of germ that invades cells and multiplies inside them. Diseases caused by viruses include the common cold, measles, and influenza.

VITAMINS
One of a number of substances, including vitamins A and C, needed in small amounts in your diet to keep your body healthy.

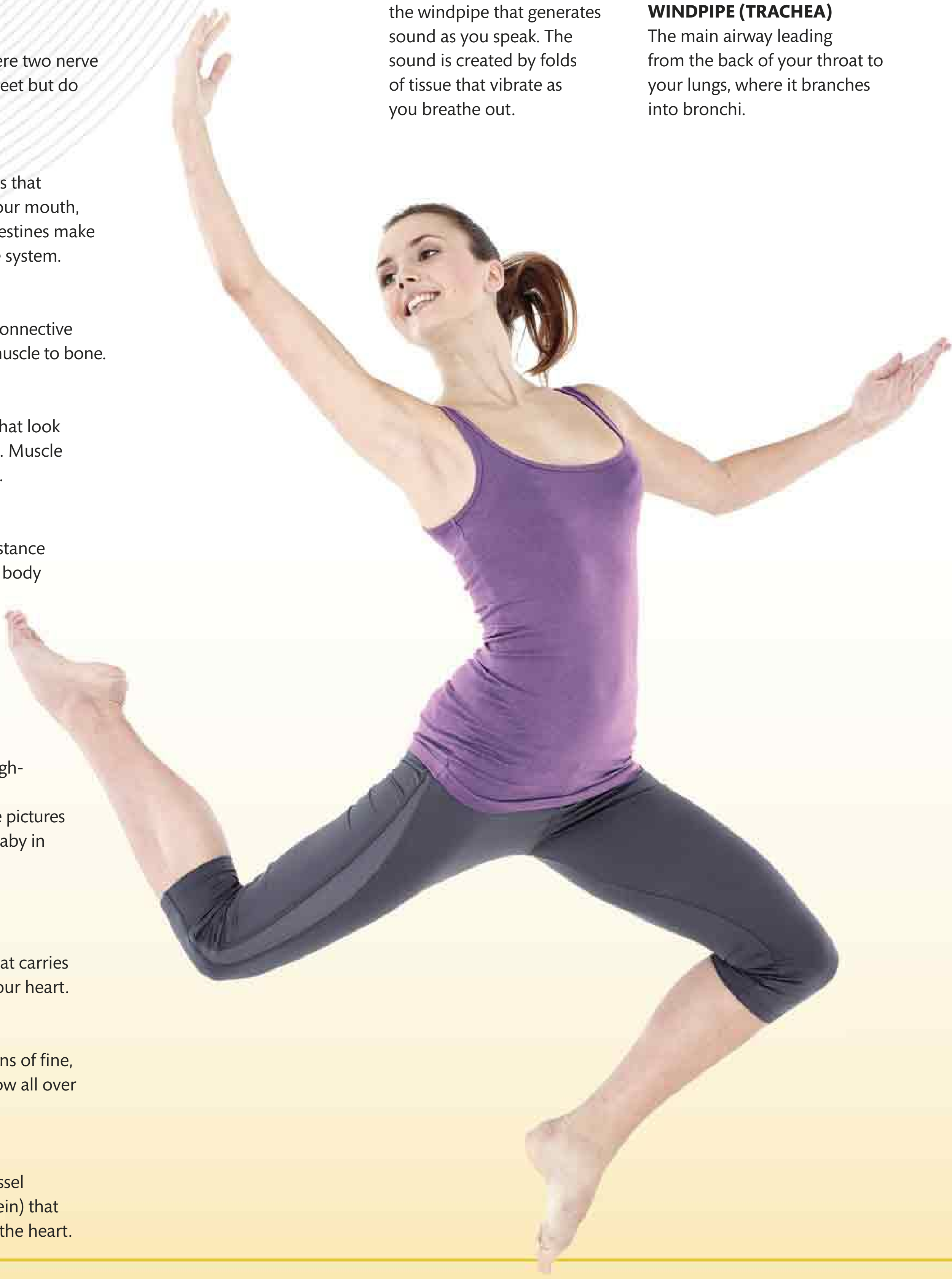
VOCAL CORDS
The small folds of tissue in your voice box that vibrate to create the sounds of speech.

VOICE BOX (LARYNX)
A structure at the top of the windpipe that generates sound as you speak. The sound is created by folds of tissue that vibrate as you breathe out.

WHITE BLOOD CELL
Any of the colourless blood cells that play various roles in your immune system.

WHITE MATTER
Brain tissue made up mainly of the axons (long fibres) of nerve cells. The inner part of the brain consists largely of white matter.

WINDPIPE (TRACHEA)
The main airway leading from the back of your throat to your lungs, where it branches into bronchi.



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Page numbers in **bold** indicate main treatment of a topic.

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