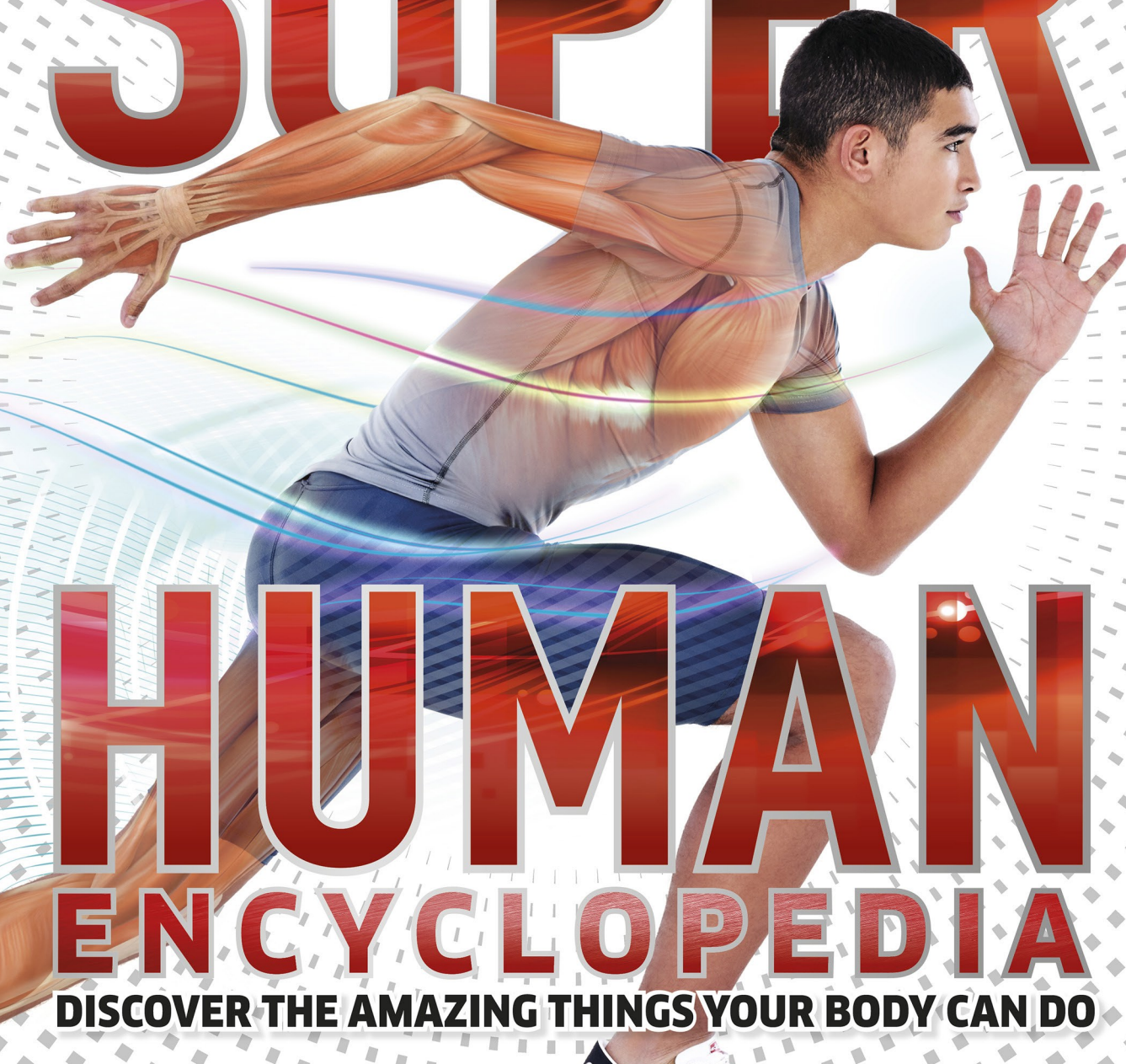




SUPER



HUMAN

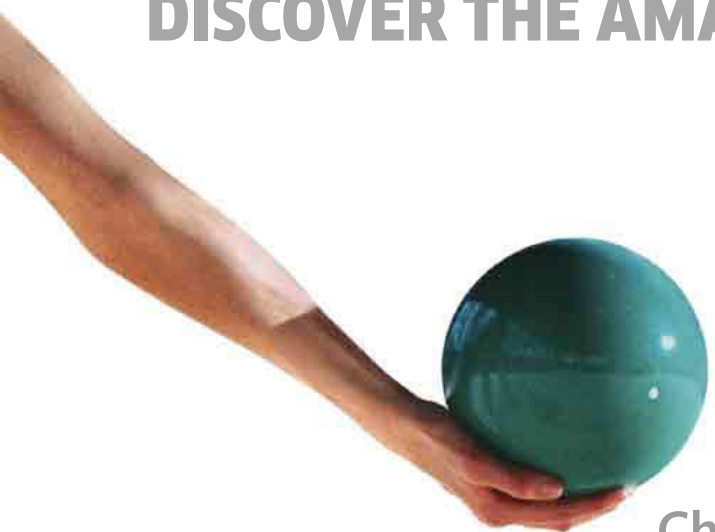
ENCYCLOPEDIA

DISCOVER THE AMAZING THINGS YOUR BODY CAN DO



SUPER HUMAN ENCYCLOPEDIA

DISCOVER THE AMAZING THINGS YOUR BODY CAN DO

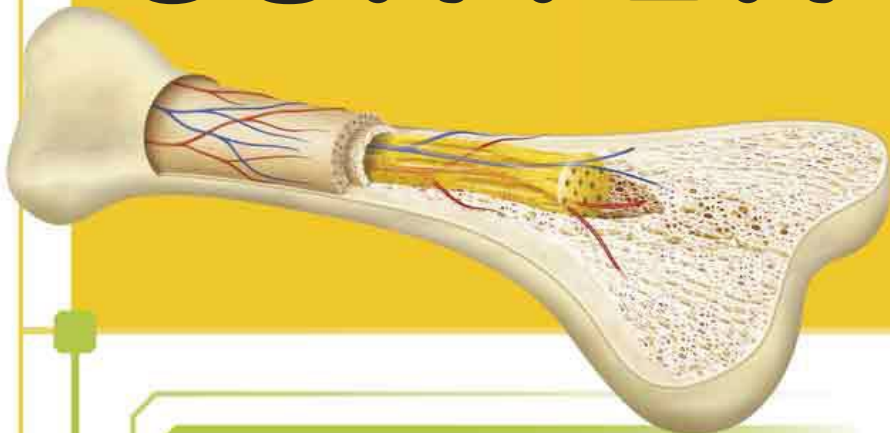


Steve Parker

Chief editorial consultant
Professor Robert Winston



CONTENTS



BODY FRAMEWORK

BODY ARMOR	22
SWEAT AND SHIVER	24
ICY PLUNGE	26
FINISHING TOUCHES	28
CUTTING EDGE	30
BODY SUPPORT	32
SUPER LEVERS	34
BARE BONES	36
BEND AND SWIVEL	38
FLIPPING OUT	40
TOTALLY SMOOTH	42
FLEX IT!	44
SUPER SPRINTER	46
TEAMWORK	48
SUPER STRENGTH	50

MISSION CONTROL

TOTAL INTRANET	54
FLYING HIGH	56
INSIDE THE MEGAWEB	58
BRAIN BUILDERS	60
PROCESSING POWER	62
LIVING DANGEROUSLY	64
ACTION STATIONS	66
LIGHTNING STRIKE	68
LOOK OUT!	70
TOTAL RECALL	72
BRAIN DOWNTIME	74

DK LONDON

Project Art Editors
Francis Wong, Clare Joyce,
Alison Gardner, Duncan Turner

Jacket Designer
Mark Cavanagh

**Jacket Design
Development Manager**
Sophia M.T.T

Pre-production Producer
Francesca Wardell

Senior Producer
Mary Slater

Senior Editor
Janet Mohun

Editors
Wendy Horobin,
Ruth O'Rourke-Jones

US Senior Editor
Margaret Parrish

US Editor
Jill Hamilton

Jacket Editor
Maud Whatley



**LONDON, NEW YORK, MELBOURNE,
MUNICH, AND DELHI**

Managing Art Editor
Michelle Baxter

Art Director
Philip Ormerod

Publishing Director
Jonathan Metcalf

Managing Editor
Angeles Gavira Guerrero

Publishers
Sarah Larter, Liz Wheeler

Associate Publishing Director
Liz Wheeler

DK INDIA

Senior Art Editor
Devika Dwarkadas

Art Editors
Parul Gambhir,
Konica Juneja,
Vanya Mittal

Managing Art Editor
Sudakshina Basu

Senior DTP Designer
Neeraj Bhatia

DTP Designers
Jaypal Singh Chauhan,
Syed Md. Farhan

Senior Editor
Anita Kakar

Editor
Susmita Dey

Managing Editor
Rohan Sinha

Production Manager
Pankaj Sharma

Pre-production Manager
Balwant Singh

Picture Researcher
Aditya Katyal

HUMAN PLANET 8

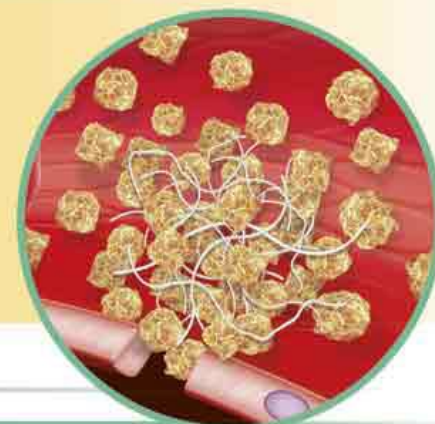
WHAT IS A HUMAN? 12

MINIATURE WORLD 16

ALL SHAPES AND SIZES 10

WORKING TOGETHER 14

THE HUMAN CODE 18

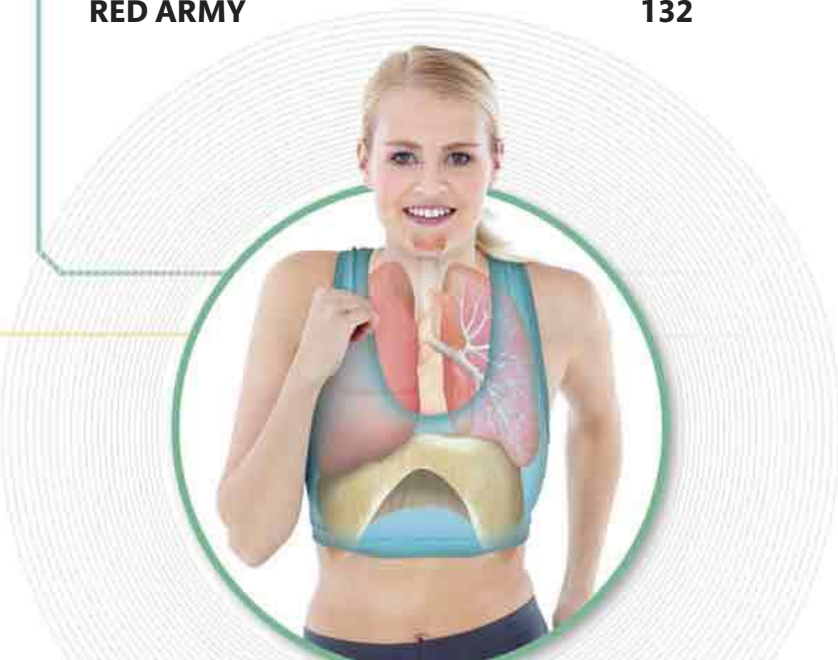


TOTALLY SENSATIONAL

STAYING FOCUSED	78
HAWKEYE	80
SEEING THE LIGHT	82
READY TO FIRE	84
KEEP IT IN PERSPECTIVE	86
COMPLETE CONTROL	88
WIRED FOR SOUND	90
HAIRS THAT HEAR	92
BALANCING ACT	94
SUPER BALANCE	96
TASTY!	98
ON THE TONGUE	100
ON THE SCENT	102
KEEPING IN TOUCH	104
FEELING GROOVY	106
THAT HURTS!	108

POWER SYSTEMS

BREATHING MACHINE	112
TAKE A DEEP BREATH	114
HUMAN SUB	116
SCREAM AND SHOUT	118
CIRCULATION CENTRAL	120
BODY PUMP	122
DOORSTEP DELIVERY	124
FIGHTING G-FORCE	126
BLOOD SUPERHIGHWAY	128
CLIMBING HIGH	130
RED ARMY	132



Illustrations Peter Bull Studios
Photography Ruth Jenkinson

Additional text Chris Woodford
Consultant Frances Ashcroft

First American Edition, 2014
Published in the United States by

DK Publishing
4th floor, 345 Hudson Street
New York, New York 10014

14 15 16 17 18 10 9 8 7 6 5 4 3 2 1
001—192974—Sept/2014

Copyright © 2014 Dorling Kindersley Limited
All rights reserved

Without limiting the rights under copyright reserved above, no part of this publication may be reproduced, stored in or introduced into a retrieval system, or transmitted, in any form or by any means (electronic, mechanical, photocopying, recording, or otherwise), without the prior written permission of both the copyright owner and the above publisher of this book.

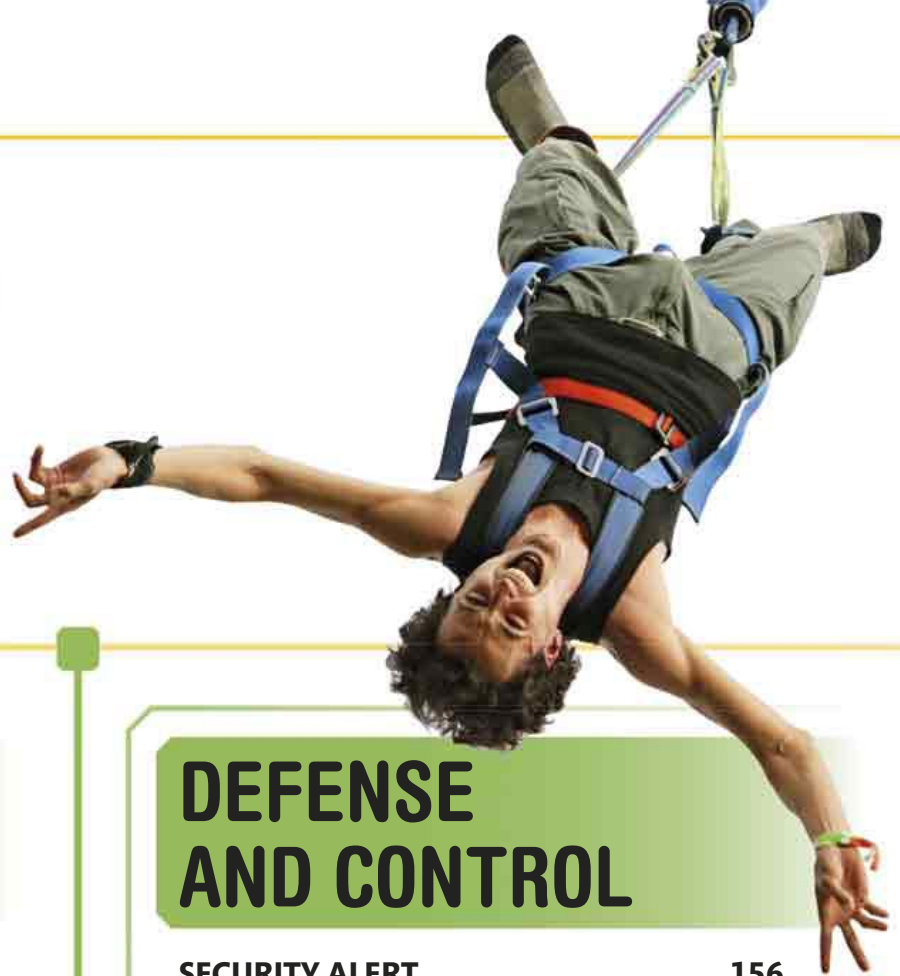
A catalog record for this book is available from the Library of Congress.

ISBN 978-1-4654-2445-7

Printed and bound in China by Leo Paper Products

Discover more at
www.dk.com

DK books are available at special discounts when purchased in bulk for sales promotions, premiums, fund-raising, or educational use. For details, contact: DK Publishing Special Markets, 345 Hudson Street, New York, New York 10014 or SpecialSales@dk.com.

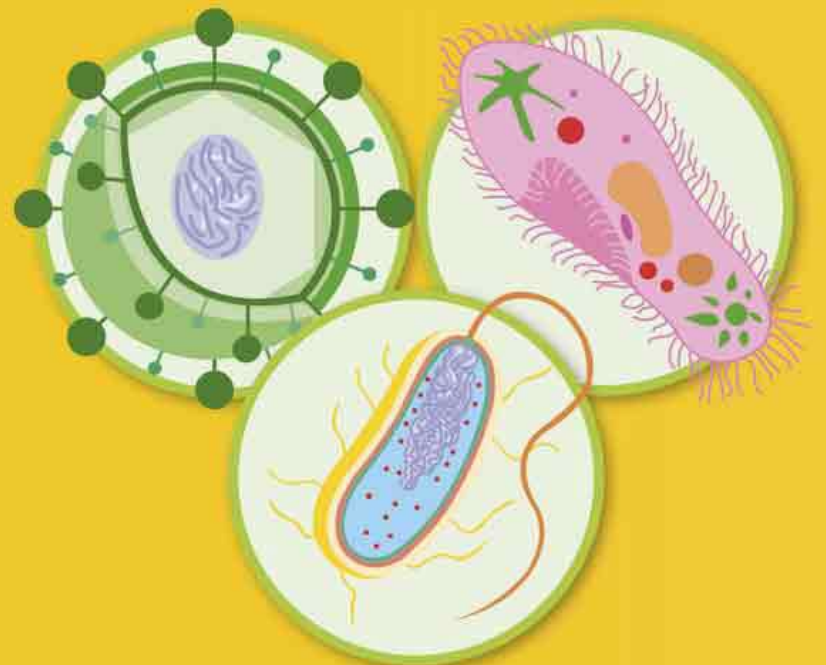


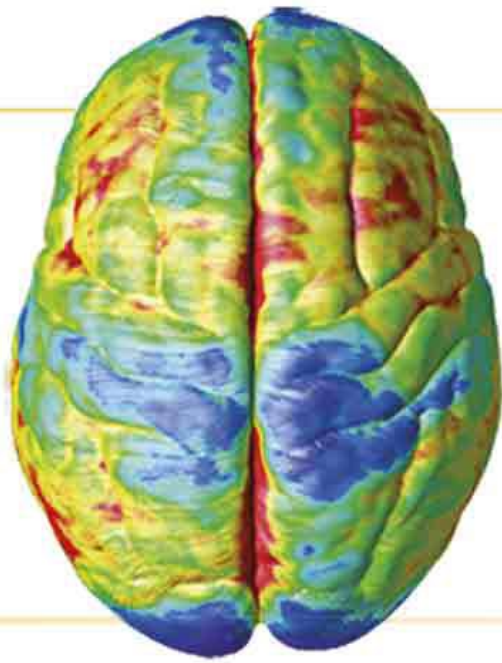
FUEL AND WASTE

FUELING THE BODY	136
DOWN THE HATCH	138
ACID BATH	140
ULTIMATE ACID PIT	142
GUT REACTIONS	144
FUEL UP!	146
PUMPING UP THE POWER	148
DETOX CENTRAL	150
PURIFICATION PLANT	152

DEFENSE AND CONTROL

SECURITY ALERT	156
ON THE ATTACK	158
SEEK AND DESTROY	160
RUNNING REPAIRS	162
BODY CONTROLLERS	164
DANGER, DANGER!	166
THRILLS AND SPILLS	168





NEW LIFE AND GROWTH

MAKING A SUPERHUMAN IN THE WOMB	172
NEW KIDS ON THE BLOCK	176
GROWING UP	178
TEEN TIME	180
PHYSICAL PROGRESS	182

FUTURE HUMANS

STAYING ALIVE	186
TO BOLDLY GO	188
SPARES AND REPAIRS	190
BIONIC BODIES	192
ALL IN THE GENES	194
BRAIN GAINS	196
THE NEXT GENERATION	198



GLOSSARY 200

ACKNOWLEDGMENTS 208

INDEX 203



HUMAN PLANET

Where we live

Humans have adapted to almost every corner of planet Earth. From the coldest poles and steepest mountains to sweltering rain forests and scorching deserts, people survive and thrive. Of course, this is partly due 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.



RAIN FORESTS

People living in tropical forests tend to have a smallish, slim stature and wear little clothing. They have sharp 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.





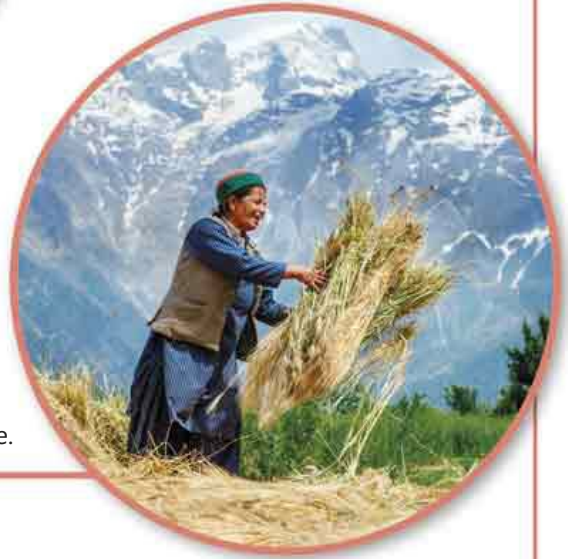
POLAR REGIONS

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.



UNDERWATER

Divers can stay under 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 color, 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”**

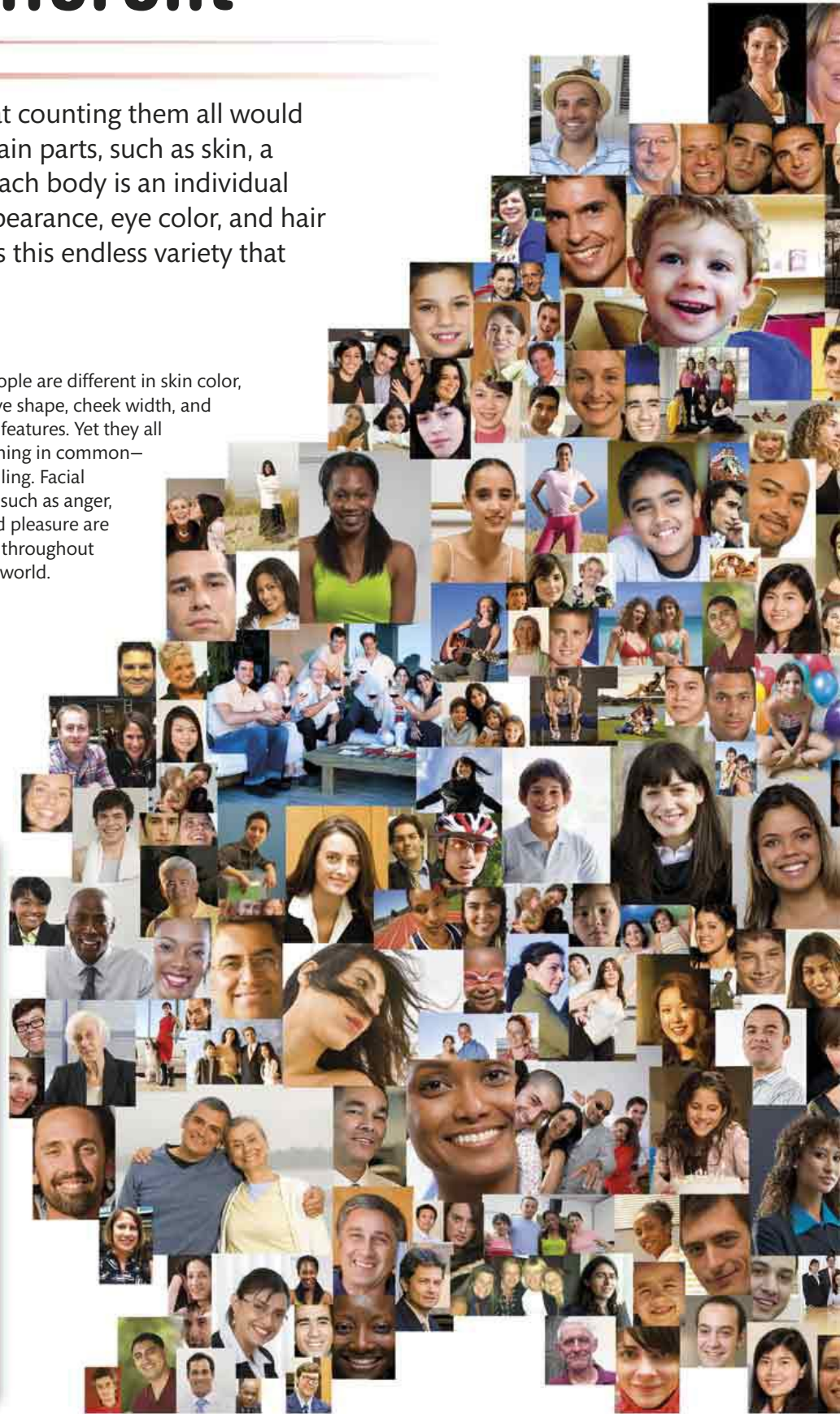
ALMOST IDENTICAL

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 favorite foods, fashions, and friends.

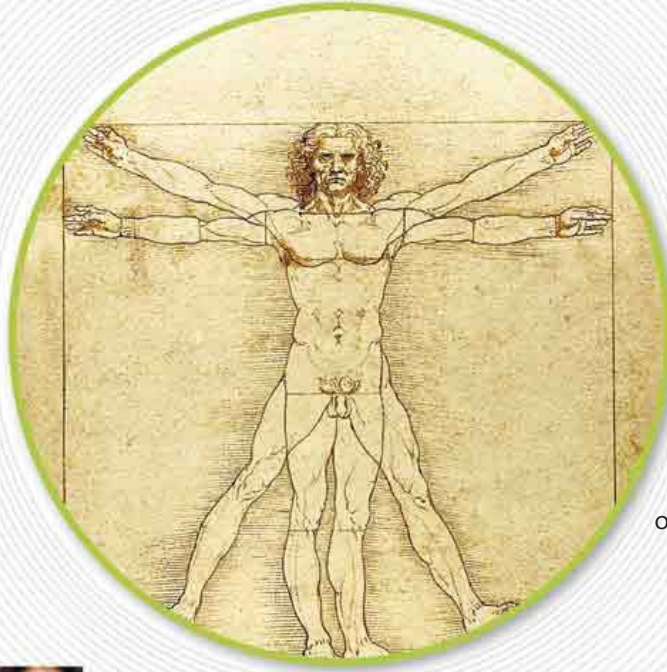


All smiles

All these people are different in skin color, 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.

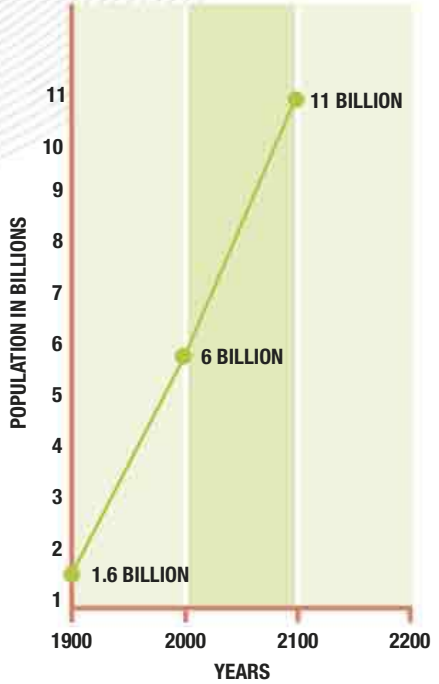


THE YEAR THE MOST HUMANS WERE BORN—1963



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.

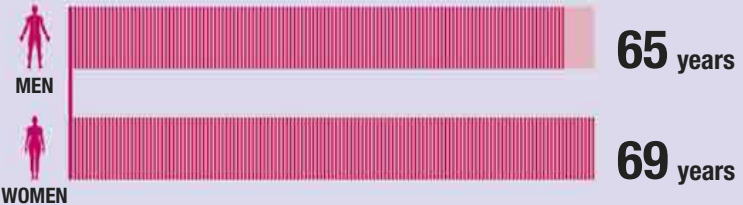


RAPID GROWTH

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



300 MILLION TONS (270 MILLION TONNES) **= 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 $\frac{1}{50}$ th of total weight. Large, folded surface allows thinking and intelligence. Protected by skull.



EYES

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



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.



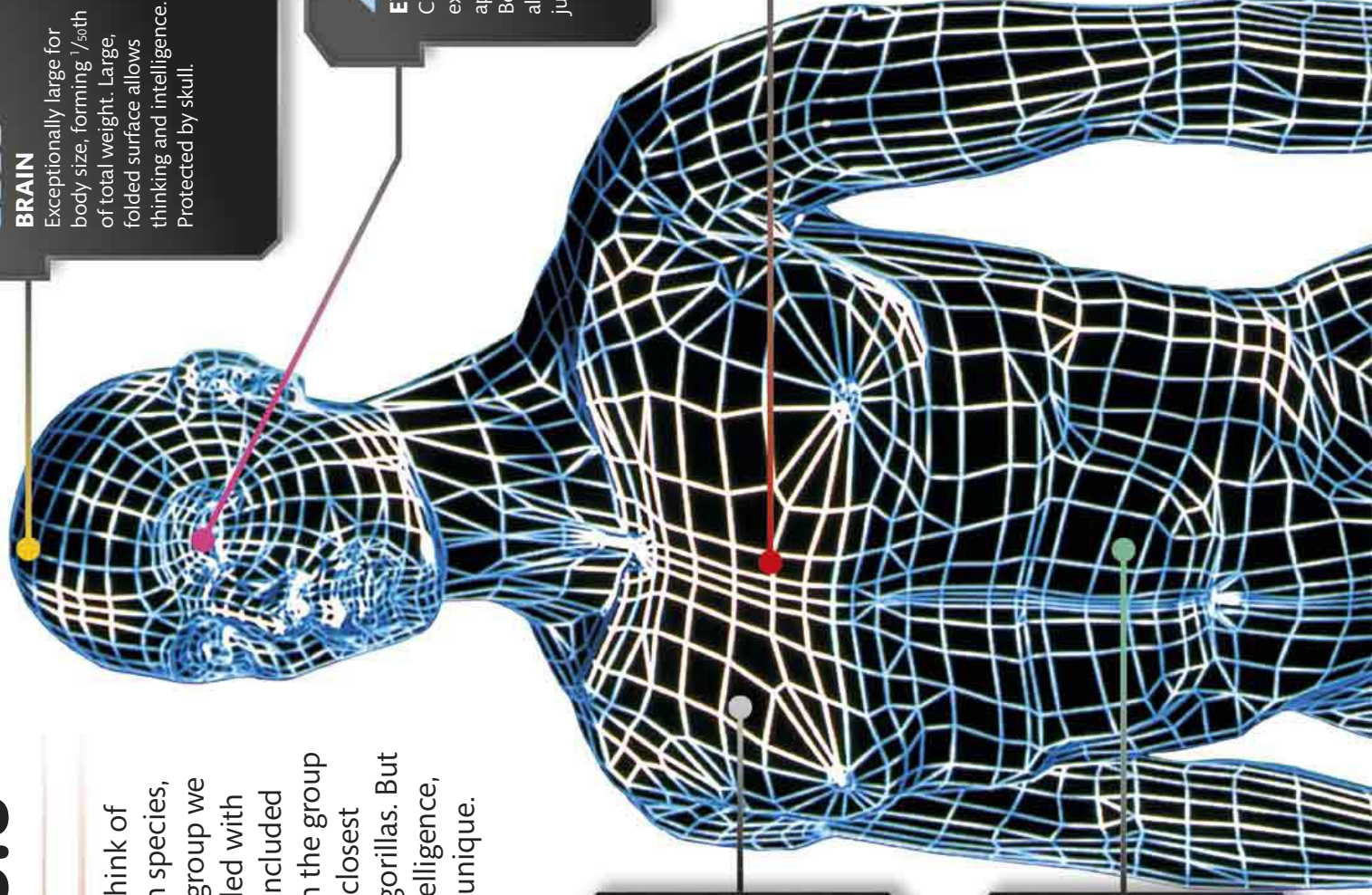
LUNGS

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.

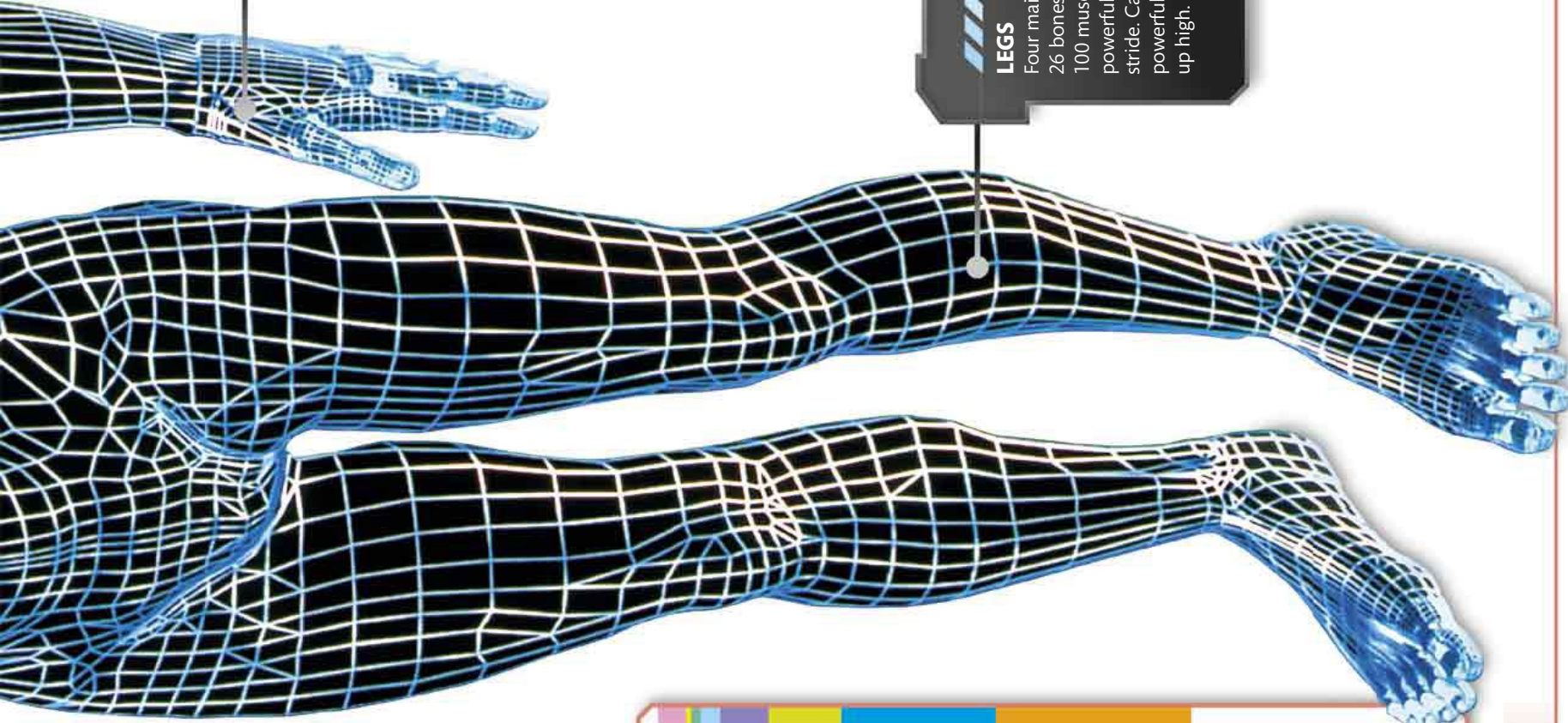


DIGESTIVE SYSTEM

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’”



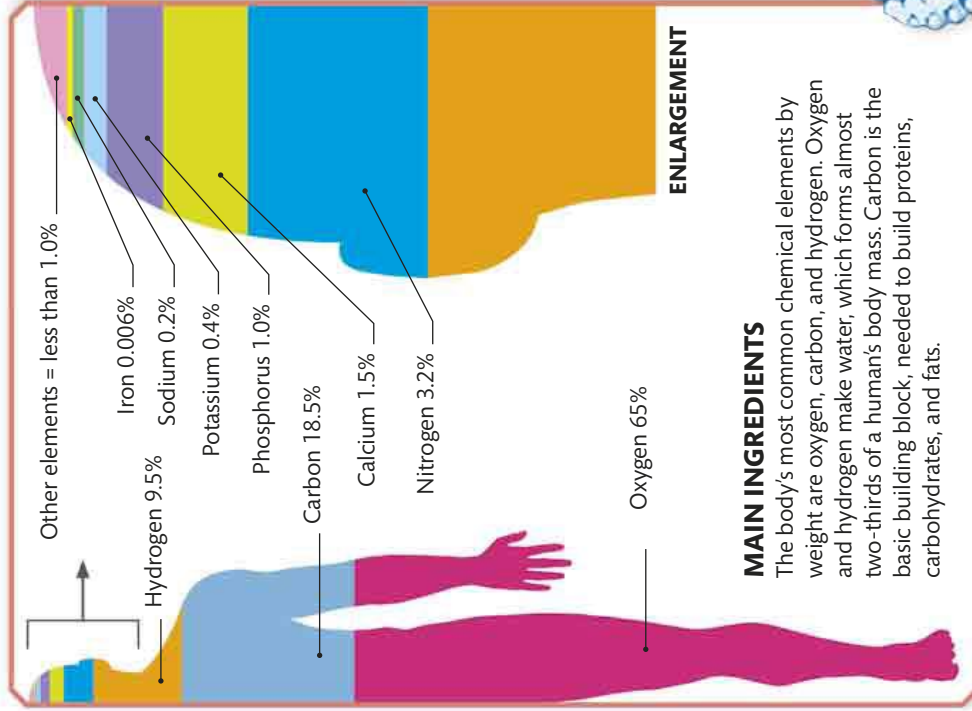
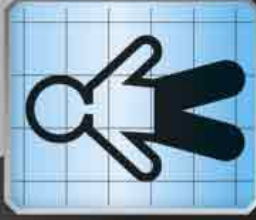
HANDS

Over 30 muscles and 27 bones combine to make an amazing grablike 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

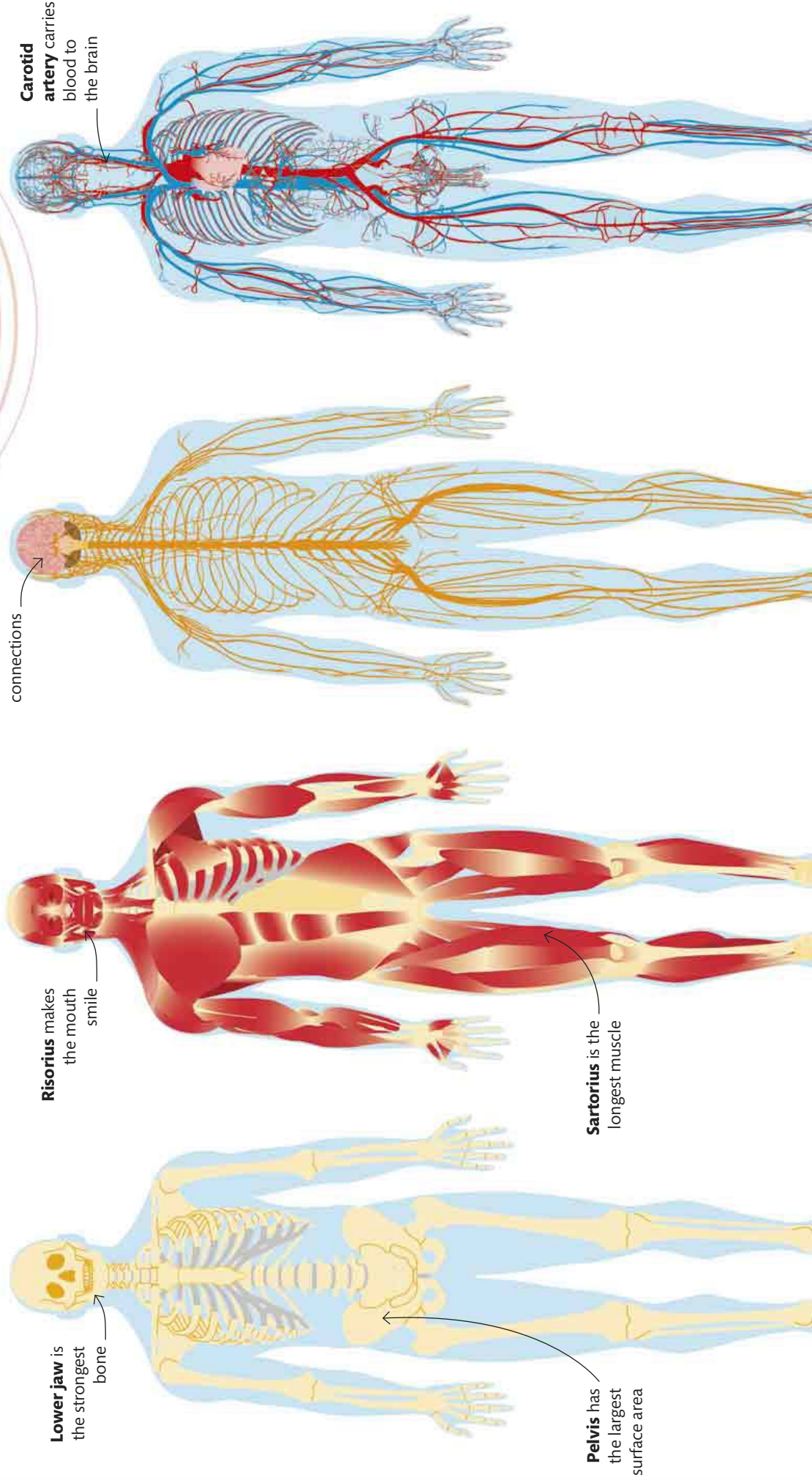
The body's most common chemical elements by weight are oxygen, carbon, and hydrogen. Oxygen and hydrogen make water, which forms almost two-thirds of a human's body mass. Carbon is the basic building block, needed to build proteins, carbohydrates, and fats.

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 Calories
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
contain about
1,560 miles
(2,500 km)
of airways

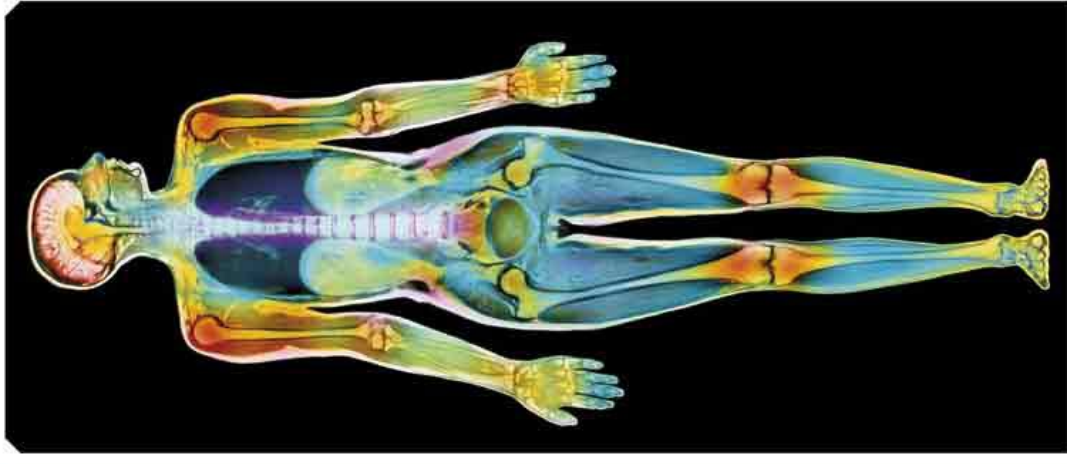
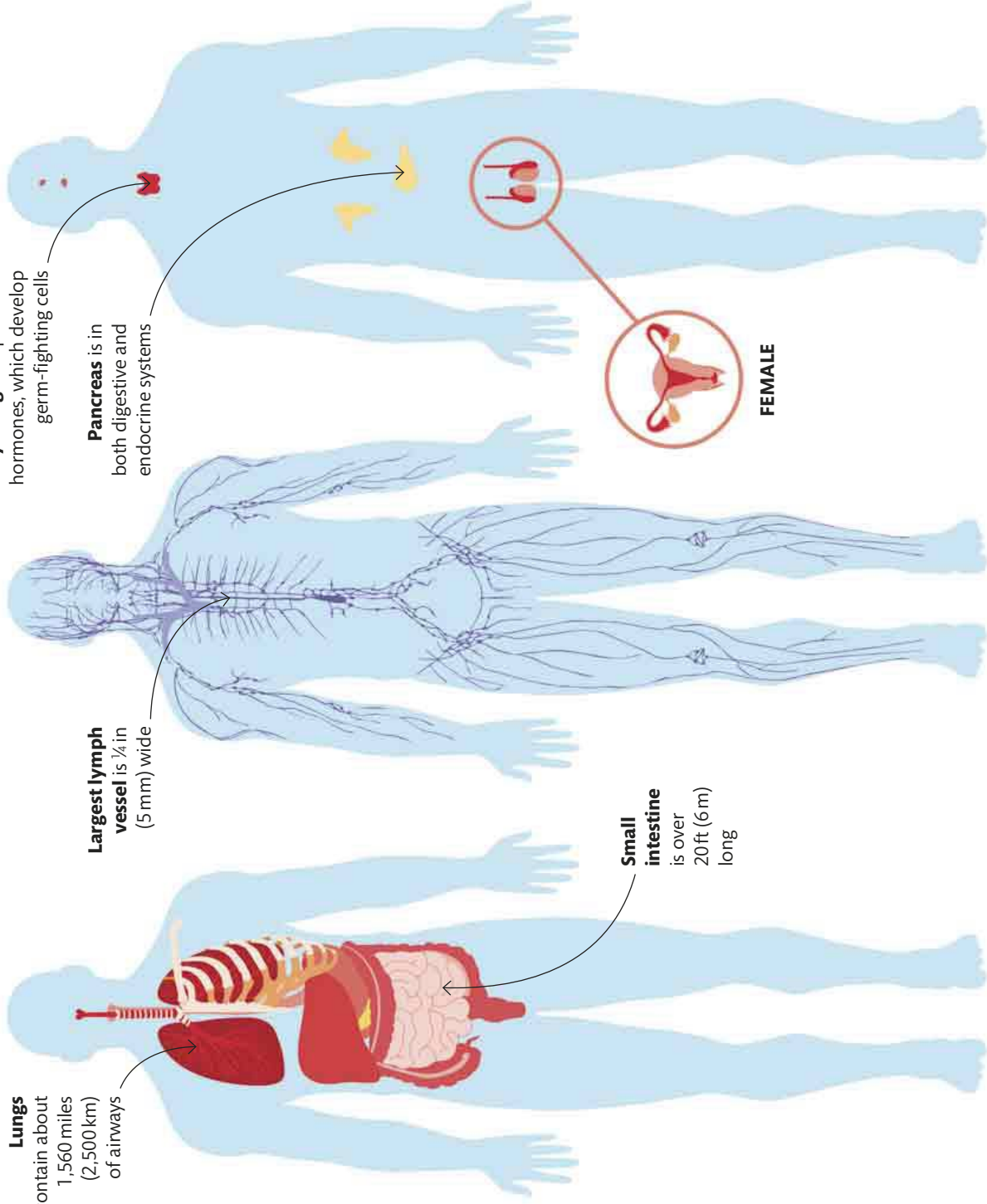
**Largest lymph
vessel**
is ¼ in
(5 mm) wide

**Small
intestine**
is over
20 ft (6 m)
long

Thymus gland produces
hormones, which develop
germ-fighting cells

Pancreas is in
both digestive and
endocrine systems

FEMALE



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.

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 microdefenders of the immune system, which is under the control of hormones.

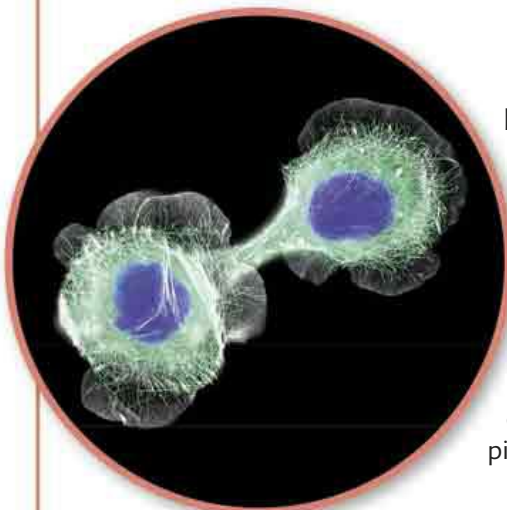
HORMONES

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

MINIATURE WORLD

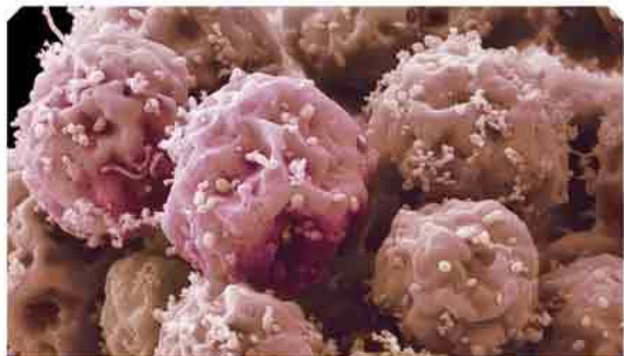
Inside a cell

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 62 miles (100 km) 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.



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 center. 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.

PARTS OF A CELL

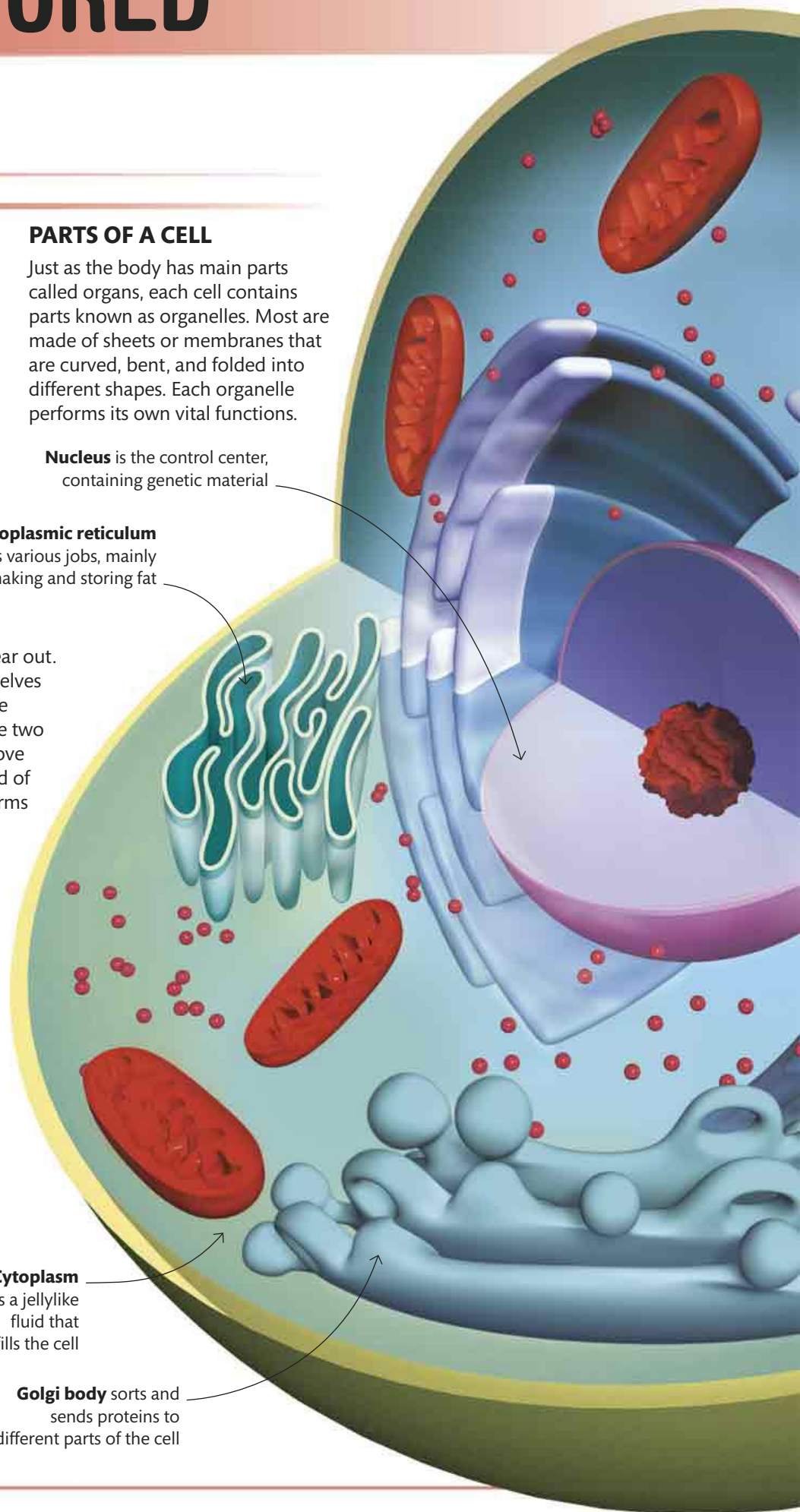
Just as the body has main parts called organs, each cell contains parts known as organelles. Most are made of sheets or membranes that are curved, bent, and folded into different shapes. Each organelle performs its own vital functions.

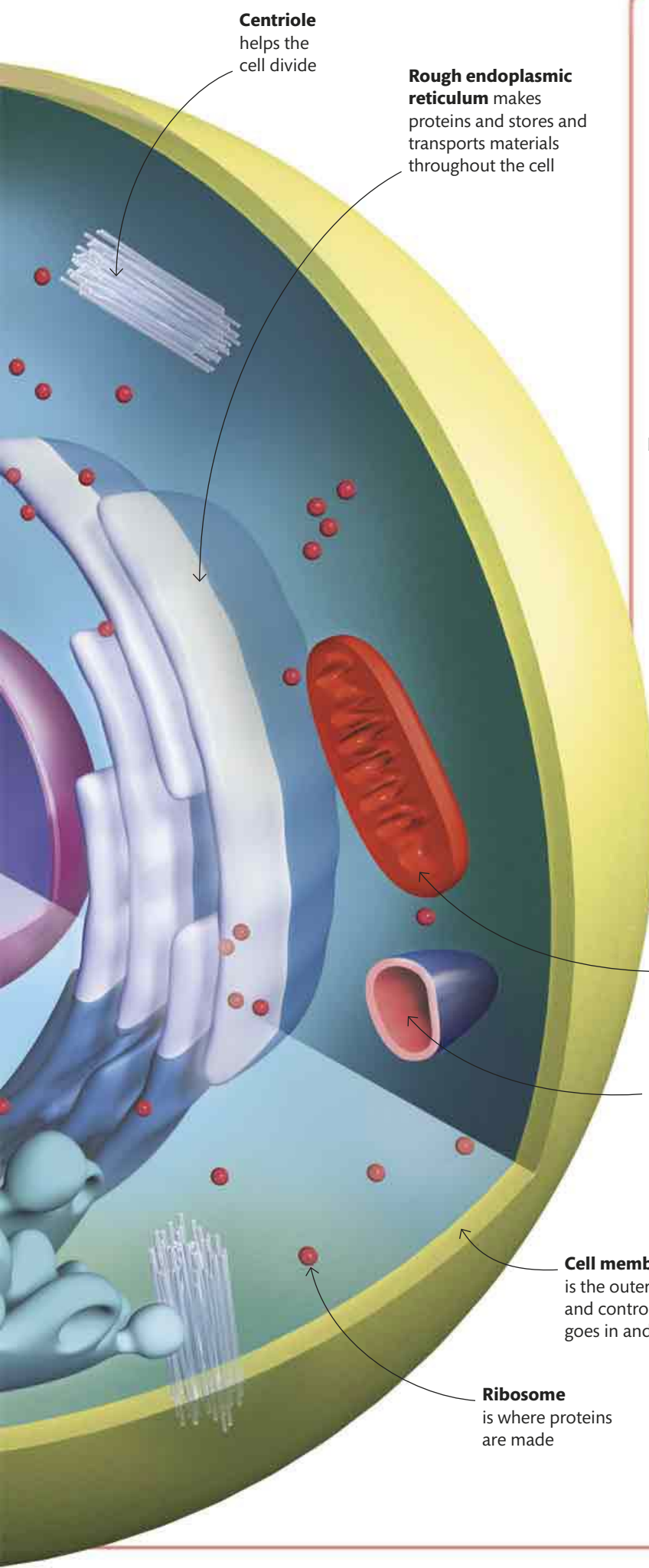
Nucleus is the control center, containing genetic material

Smooth endoplasmic reticulum does various jobs, mainly making and storing fat

Cytoplasm is a jellylike fluid that fills the cell

Golgi body sorts and sends proteins to different parts of the cell





Centriole
helps the
cell divide

**Rough endoplasmic
reticulum** makes
proteins and stores and
transports materials
throughout the cell

TYPES OF BODY CELLS

Most specialized cells include all the basic cellular parts, such as a 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.

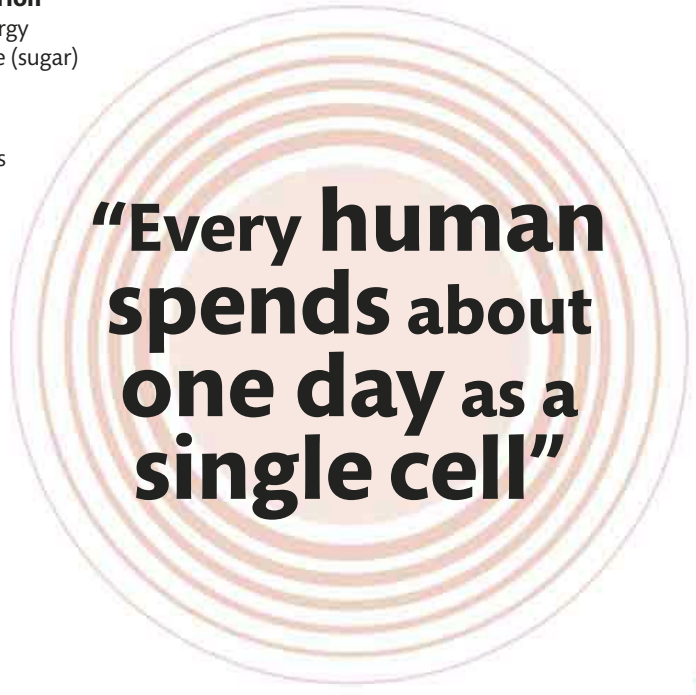
<p>EPITHELIAL CELL Shaped like bricks, blocks, or slabs, these make sheets that form coverings and linings of body parts.</p>	<p>SMOOTH MUSCLE CELL Spindle-shaped, these cells can get shorter to make muscle contract.</p>
<p>LIGHT-SENSING CELL The eye's rods and cone cells have light-sensing chemicals in one end and a nerve link at the other.</p>	<p>NERVE CELL Thin, branching arms gather nerve signals and send them along the nerve fiber.</p>
<p>RED BLOOD CELL Disk-shaped, it soaks up maximum oxygen to carry the highest amount possible in the bloodstream.</p>	<p>SPERM CELL The head carries the father's genetic material. The tail lashes to swim toward the egg.</p>
<p>ADIPOSE FAT CELL Most of the cell is filled with large blobs of fat—a valuable store of energy for tissues.</p>	<p>EGG CELL This contains the mother's genetic material and large energy stores for early cell divisions.</p>

Mitochondrion
releases energy
from glucose (sugar)

Lysosome contains
substances called
enzymes that
break down
any food the
cell absorbs

Cell membrane
is the outer covering
and controls what
goes in and out

Ribosome
is where proteins
are made



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 along 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 color.



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.

Y chromosome
has more than 200 genes

X chromosome
has 2,000 genes

Chromosome

Coils of DNA double helix are further twisted into a supercoil

Proteins act as spools for the DNA to wind around

The chemicals adenine and thymine pair up to create a rung, or base pair

Guanine and cytosine form the other base pair

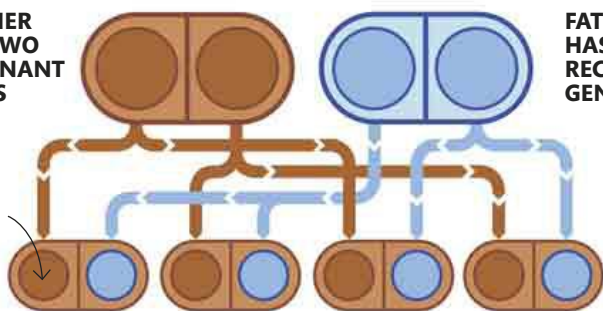
HOW GENES WORK TOGETHER

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 color may make blue eyes and the other brown. Which wins? Some genes are dominant and they beat the other ones, called recessive.

MOTHER HAS TWO DOMINANT GENES

FATHER HAS TWO RECESSIVE GENES

Brown beats blue



ALL OFFSPRING HAVE THE SAME COMBINATION

Tongue rolled into a tube

TONGUE-TIED

Recent discoveries about the body show that many features are controlled by several genes, rather than just one. Eye color, 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.



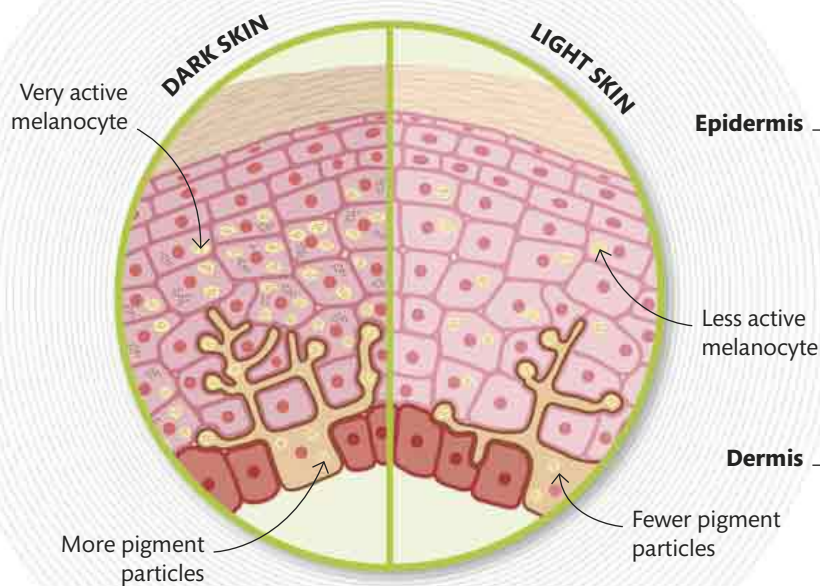
BODY FRAMEWORK

Stiff yet flexible, 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 ARMOR

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.

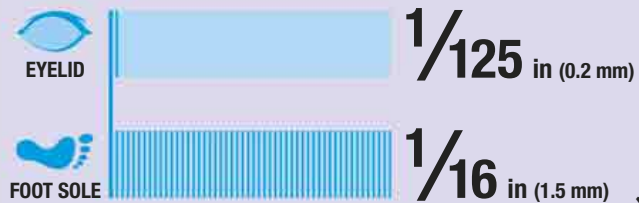


COLOR CODING

The epidermis contains colored 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



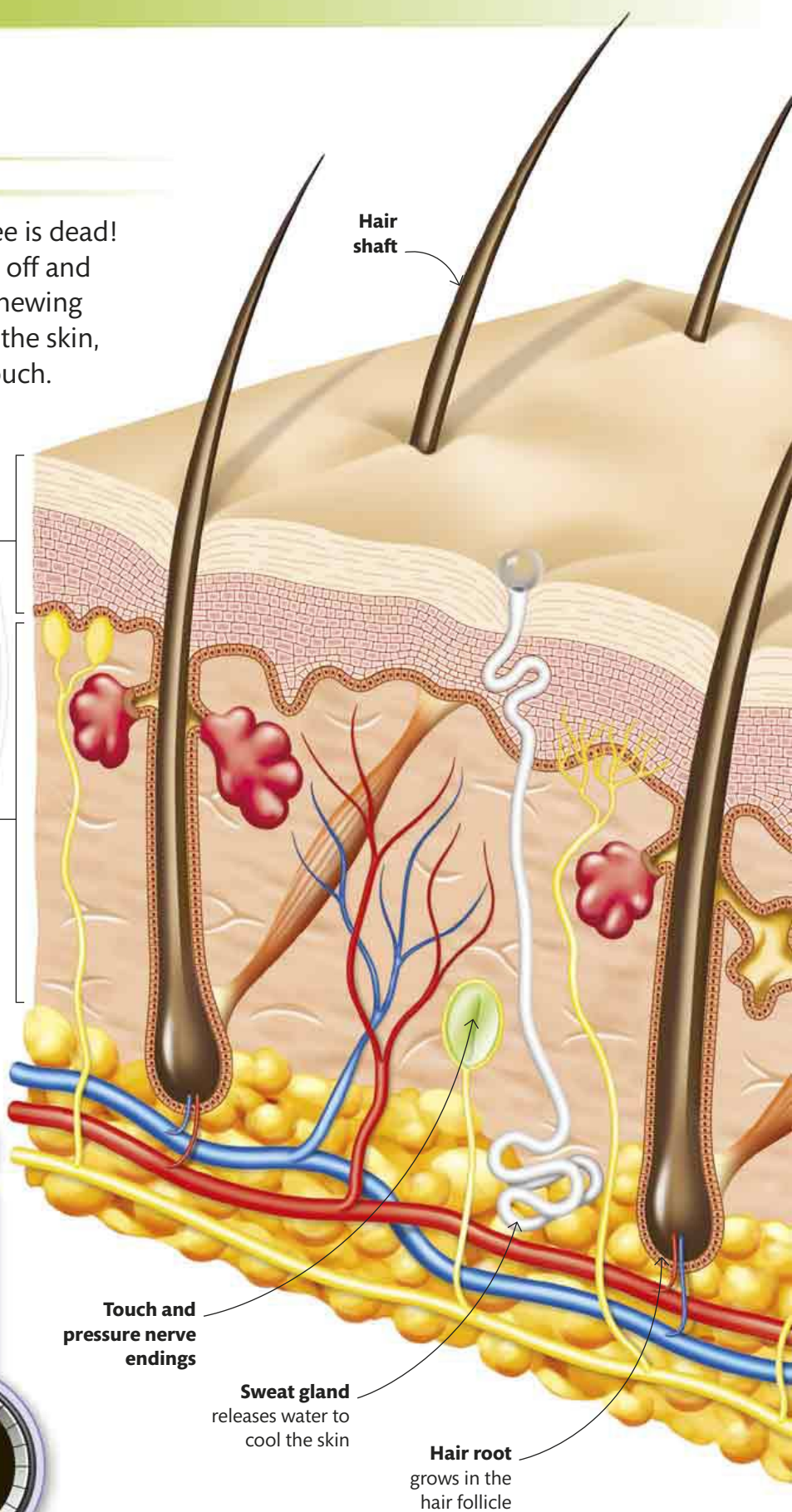
SKIN SHEDDING

50% of dust in your home is dead skin



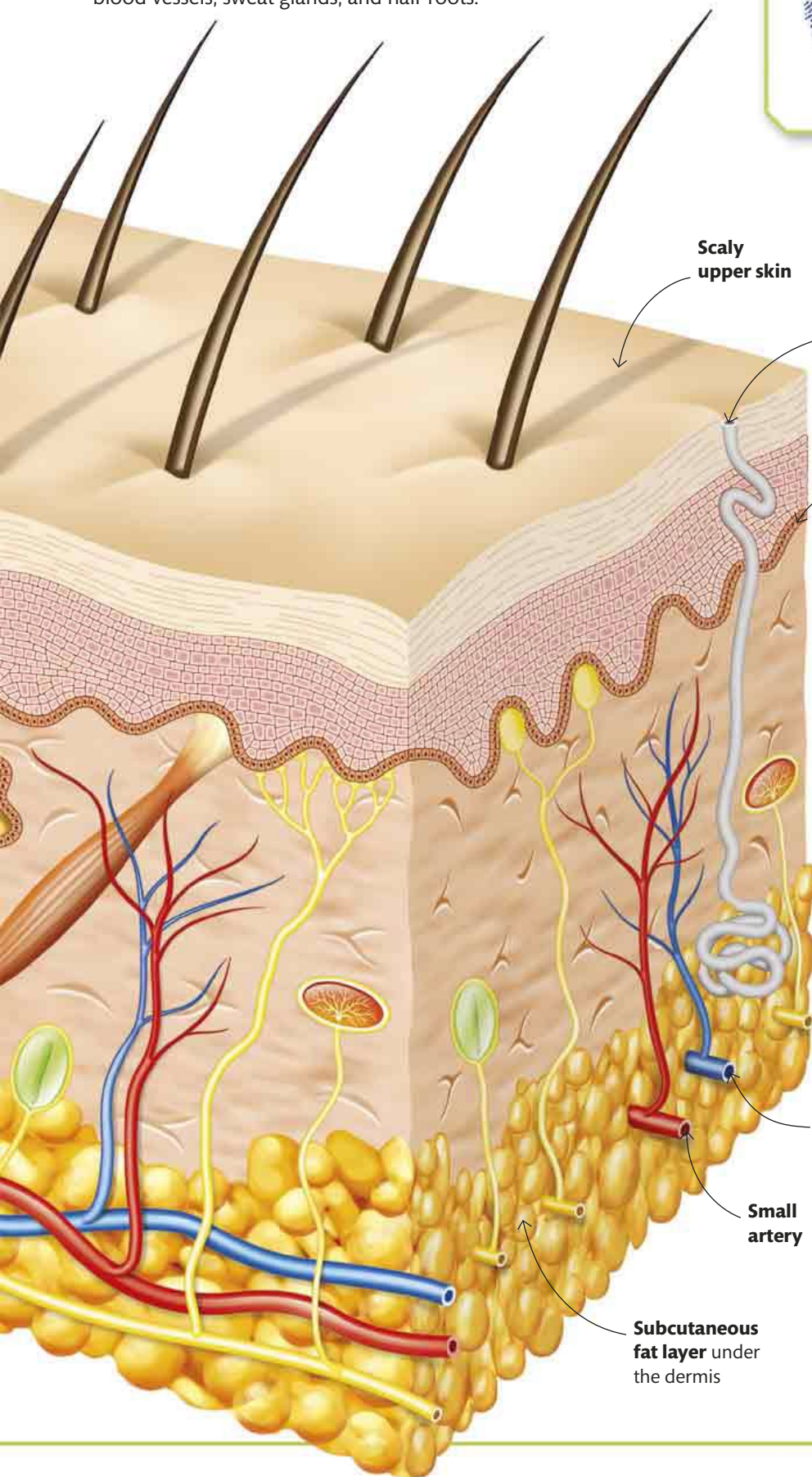
SKIN RENEWAL TIME

28 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.



LOOP



WHORL

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 closeup 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 98.6°F (37°C), give or take 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 center monitors the blood. Above about 100.4°F (38°C), the sweat glands produce watery sweat. As the sweat evaporates, it draws heat from the skin and inner parts, and cools the body down.

Athletes sweat easily because they have a more efficient body thermostat

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



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.

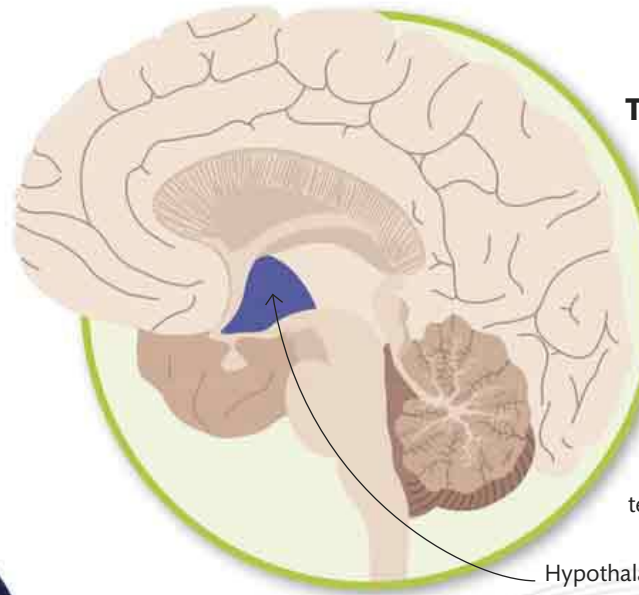
Sweat is mostly water but contains around 1% dissolved minerals

**“Shivering
can burn about
400 calories
per hour”**

Too cold

When the brain detects a fall in body temperature below around 97.7°F (36.5°C), 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.

Shivering for 10 minutes can use as many calories as an hour of exercise



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.

Hypothalamus

A hat reduces heat loss from the head



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.

Layered clothes help trap heat against the body

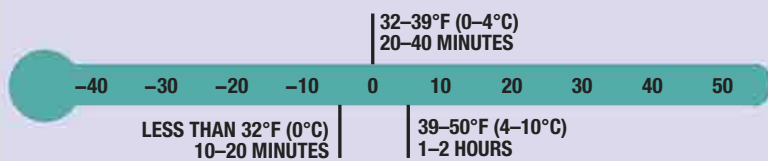
ICY PLUNGE

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

SURVIVING IN COLD WATER



POLAR SWIM

Farthest distance swum nonstop in polar waters



POLAR BEAR

427 miles
(687 km)
in 9 days



HUMAN

0.6 miles
(1 km)
in 18 minutes

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.

A high-angle photograph of a woman swimming in a body of water filled with numerous chunks of ice. The woman is in the lower-left quadrant, looking towards the camera with a determined expression. The water is dark blue, and the ice is white and translucent. In the upper-right quadrant, there is a circular graphic with concentric white lines, containing text.

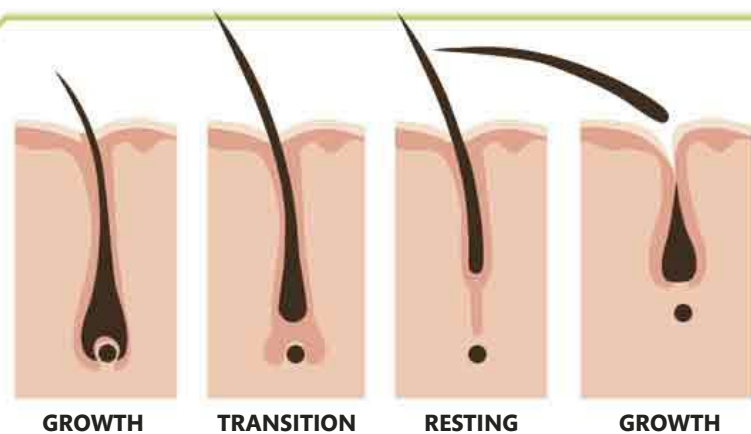
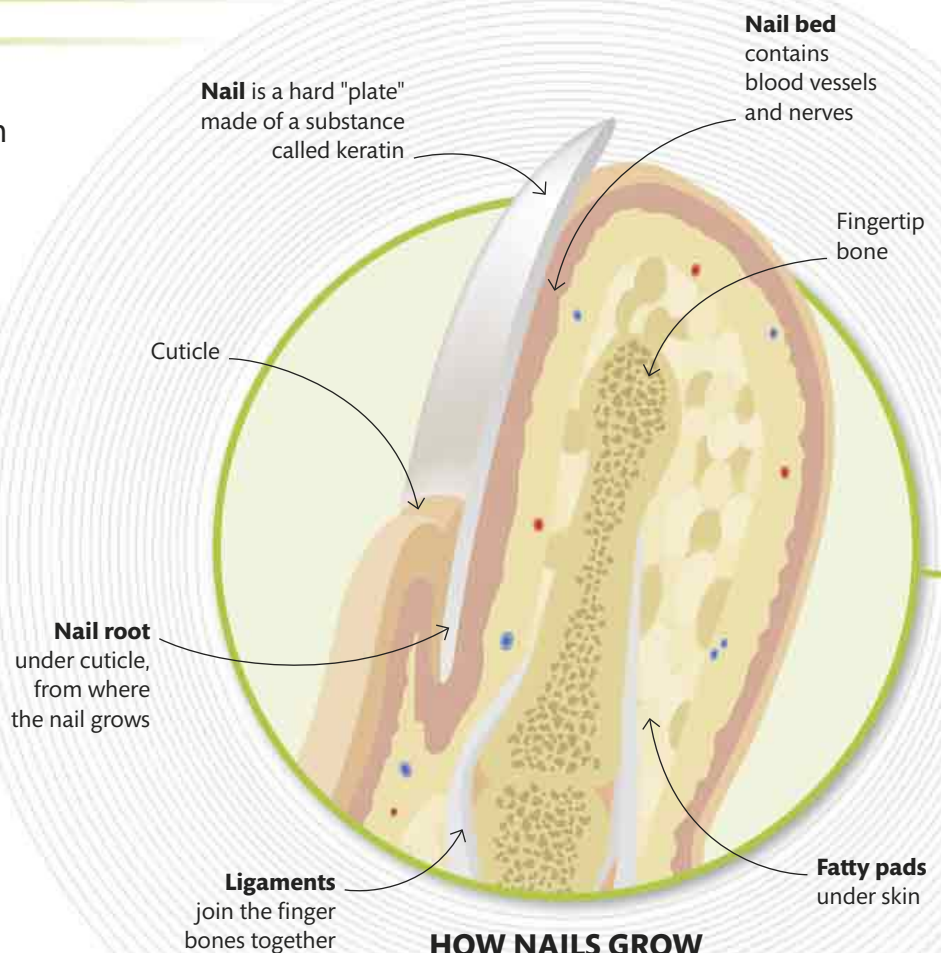
**“Cold water
takes away body
heat 30 times
faster than
cold air”**

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”



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 3 ft (1 m)—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.

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

CURLY OR STRAIGHT

The color 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 around 100,000 hairs on their heads, blondes have about 120,000 hairs, and redheads have 90,000 or fewer.



Scalp hairs protect the skin and brain from knocks, sunburn, and extreme temperatures

HAIRY ALL OVER

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

Eyebrows divert sweat and water from the eyes

Eyelashes are relatively thick and swish floating dust away from the eyes

Lower eyelid has 70-80 lashes, upper eyelid has 90-120

Facial hair is lighter, thinner, and shorter in women than men, due to genes and female hormones

The longest recorded hair is 18 ft (5.6m)

**WE LOSE
80-100 SCALP
HAIRS A DAY**

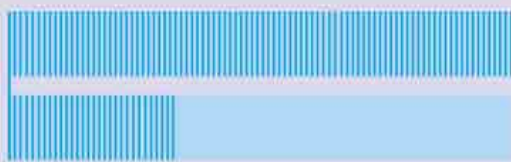
CUTTING EDGE

Nailing it

Unlike hairs, which grow, die, and fall out, nails grow day after day, year after year. They help 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
Toenail

0.5 mm
Fingernail

LONGEST SINGLE NAIL



4¹/₂ ft (1.3 m)

A fingernail grows $\frac{1}{2}$ in (1 cm) every 100 days

WATER CONTENT OF NAILS

10-15
PERCENT

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

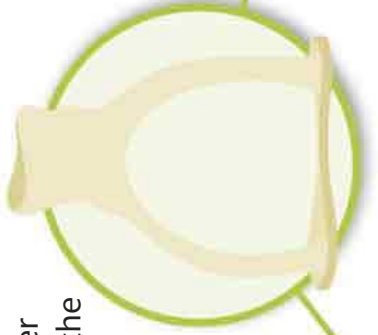
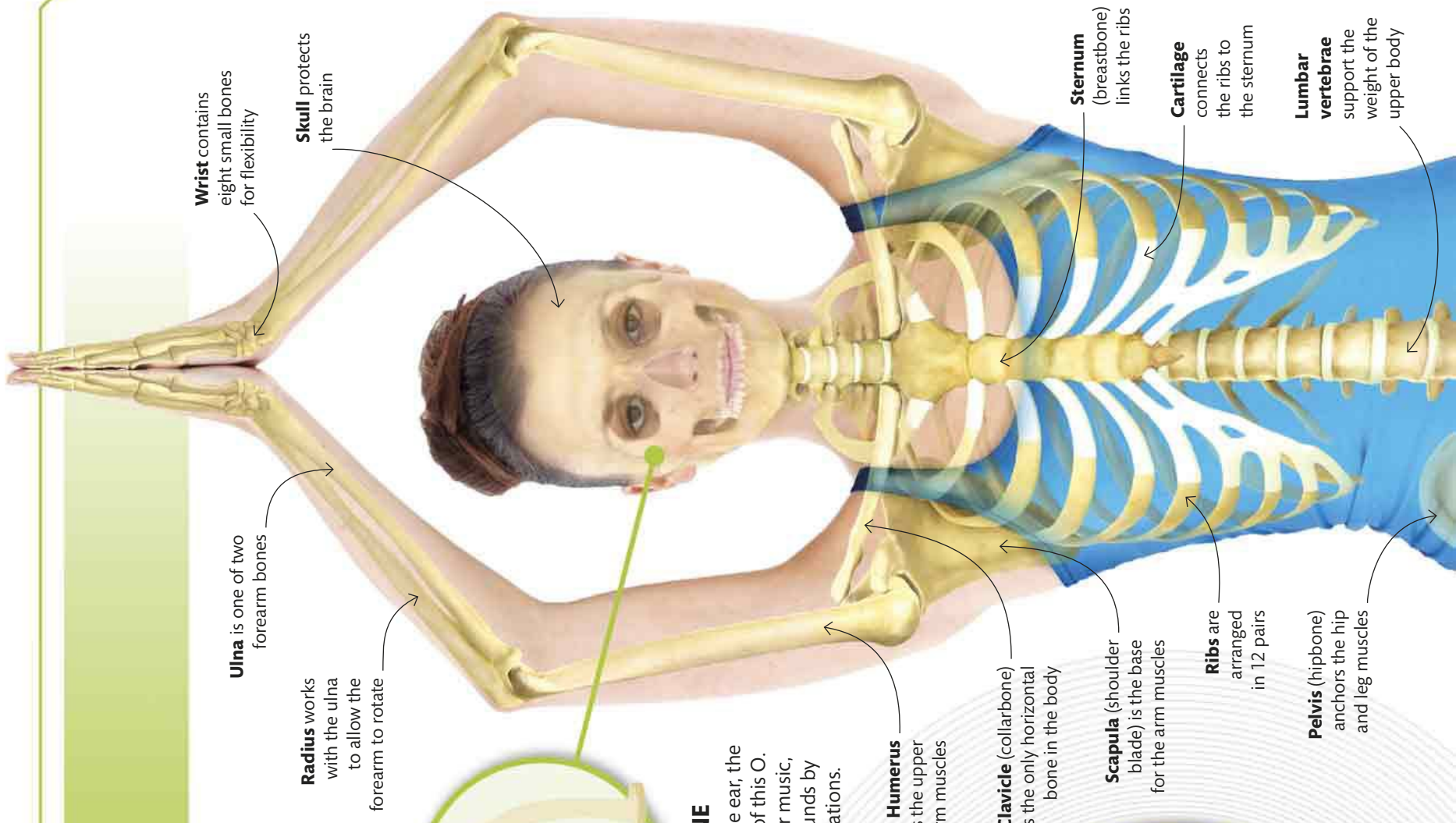
Skeleton

Far from being dry, white, and dead, your skeleton—all the bones put together—is one-quarter water, pinkish white in color, and an active part of the body. Not only does the skeleton prevent you from collapsing into a heap of meat, it is a movable 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.

YOUR SKELETON HAS 206 BONES

FLEXIBLE 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.



TINIEST BONE

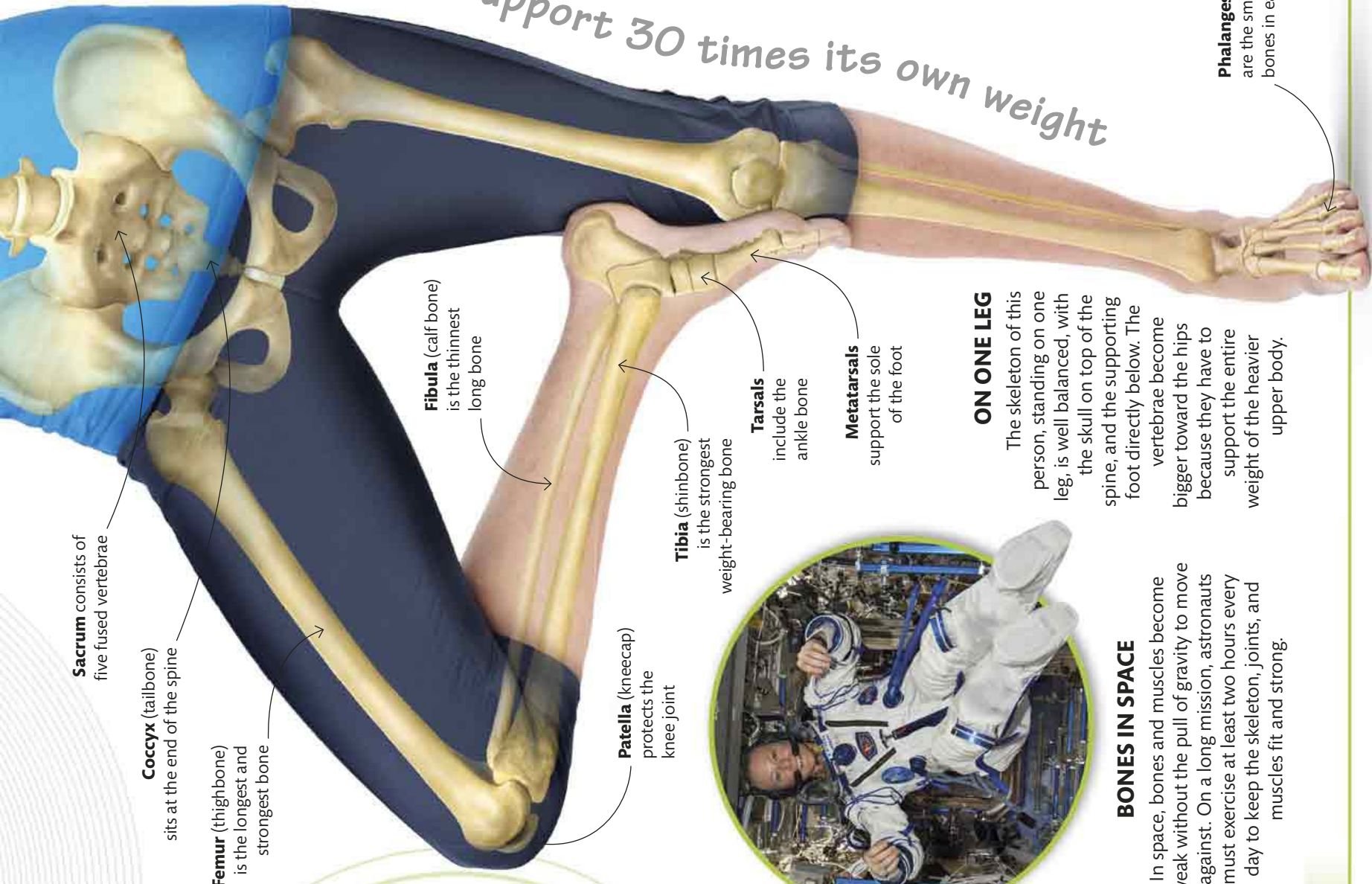
Located deep within the ear, the stirrup is just the size of this O. Yet it allows us to hear music, speech, and other sounds by passing on their vibrations.

Actual size is $\frac{1}{10}$ in (2.5 mm)



“Humans and giraffes both have seven neck bones”

The thighbone can support 30 times its own weight



Sacrum consists of five fused vertebrae

Coccyx (tailbone) sits at the end of the spine

Femur (thighbone) is the longest and strongest bone

Patella (kneecap) protects the knee joint

Fibula (calf bone) is the thinnest long bone

Tibia (shinbone) is the strongest weight-bearing bone

Tarsals include the ankle bone

Metatarsals support the sole of the foot

Phalanges are the small bones in each toe

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 toward the hips because they have to support the entire weight of the heavier upper body.



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.

STATS AND FACTS

NUMBER OF VERTEBRAE

400

Maximum number of vertebrae in a snake

33

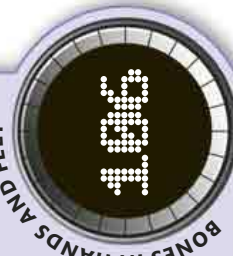
Number of vertebrae in a human

NUMBER OF BONES

206 IN ADULTS

300 IN BABIES

BONES IN HANDS AND FEET



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



LONG JUMP RECORD



CHAMPION LONG JUMPER



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.



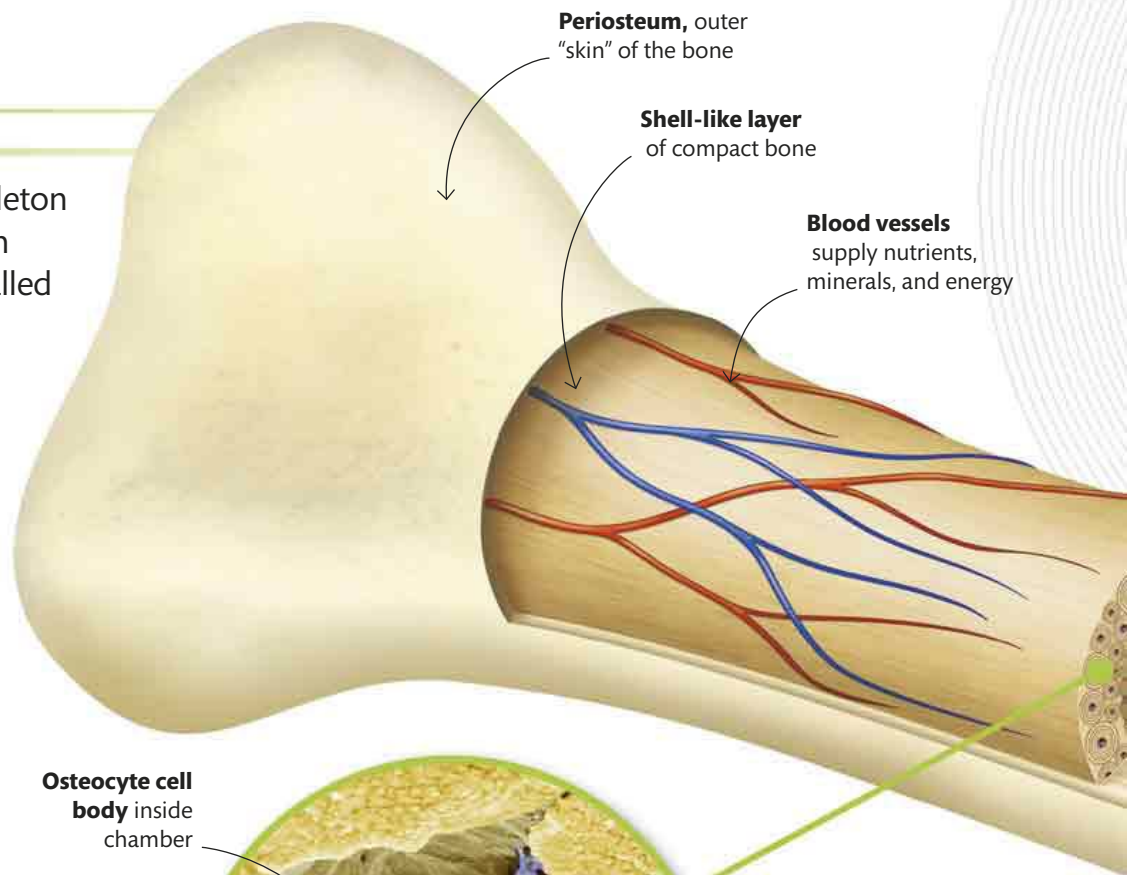
**“Champion
long jumpers
can leap 5 times
their body
length”**

BARE BONES

Inside bone

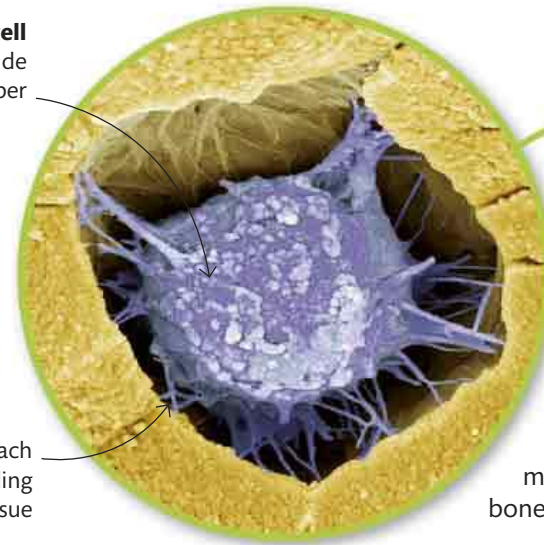
Bones are far from solid—otherwise your skeleton would be five times heavier! Each bone has an outer shell of a very strong, dense substance called compact bone. Inside it is a more spongelike layer, which has struts and rods of bone with spaces between for fluids and other tissues. This clever design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

“Bones can support more weight than concrete”



Osteocyte cell body inside chamber

“Tentacles” reach into surrounding bone tissue

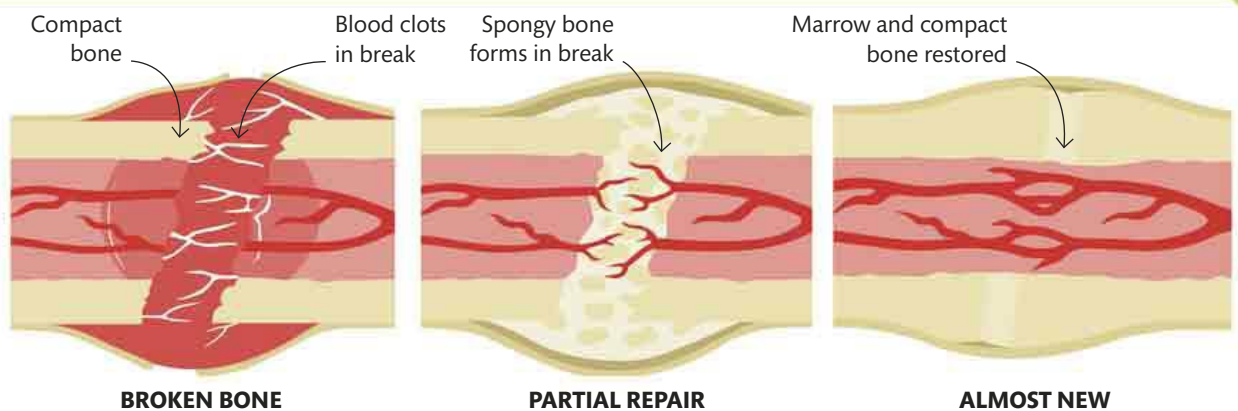


TRAPPED IN

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 maintain the surrounding bone and keep it healthy.

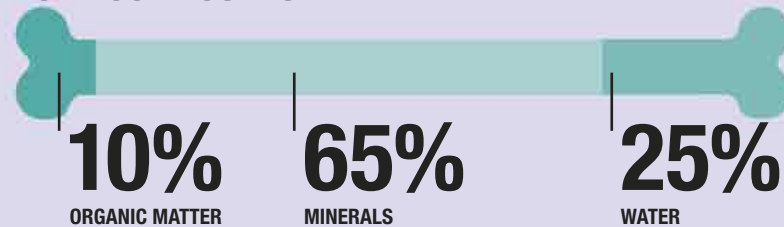
REPAIRING BONE

A broken or cracked bone starts to repair itself almost right 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 fibers that grow between the broken ends. Cells called osteoblasts then produce spongy bone that, in the outer layer, hardens into compact bone.

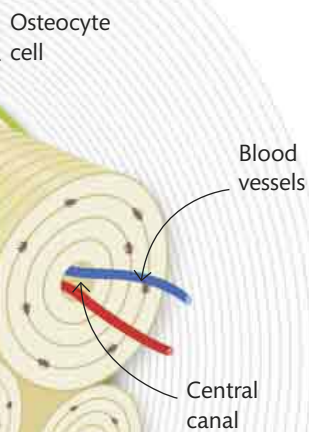
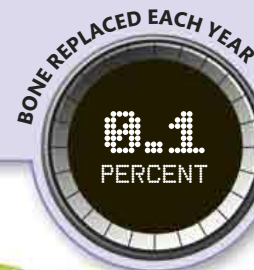
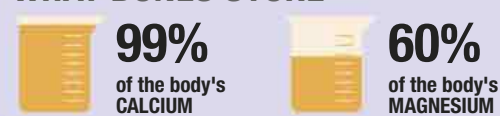


STATS AND FACTS

BONE COMPOSITION



WHAT BONES STORE



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 less than 1mm across and ¼–½ in (5–10mm) long.

THE THIGHBONE IS THE STRONGEST BONE IN THE BODY

Spongy bone has a strong and light lattice structure

Bone marrow is found in the center of long bones



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 cells—red cells, white cells, and platelets.

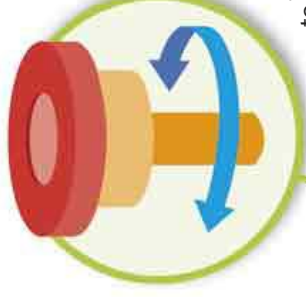
Bone shapes

A long bone, such as the femur (thighbone), has a slim but 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 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 movable joints, which occur from the jaw down to the toes. Each movable 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 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.

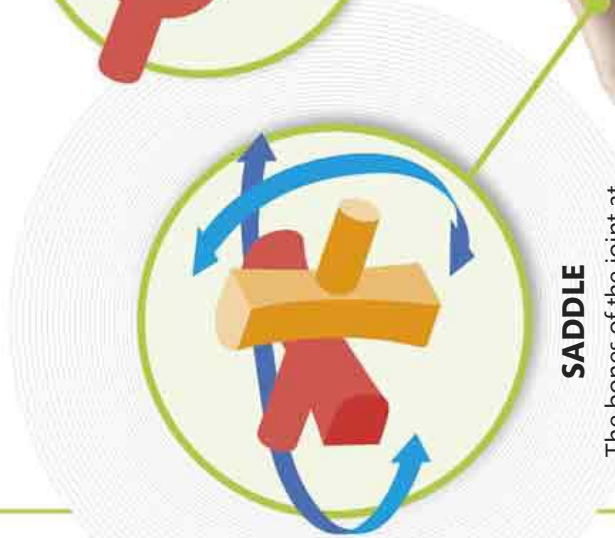
ELLIPSOIDAL

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.

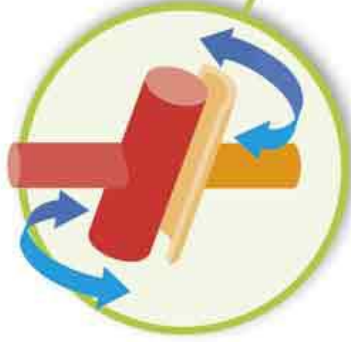


Fingers moving beyond range of normal joint



DOUBLE JOINTED

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



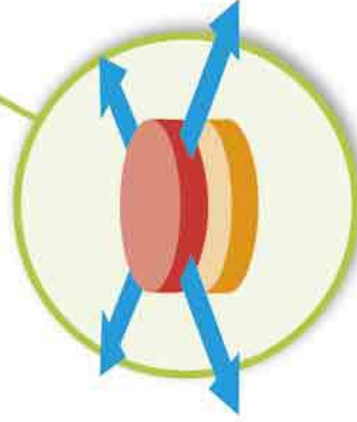
HINGE

Hinge joints in the knees and the finger and toe knuckles, let these bones move backward and forward, 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.



GLIDING

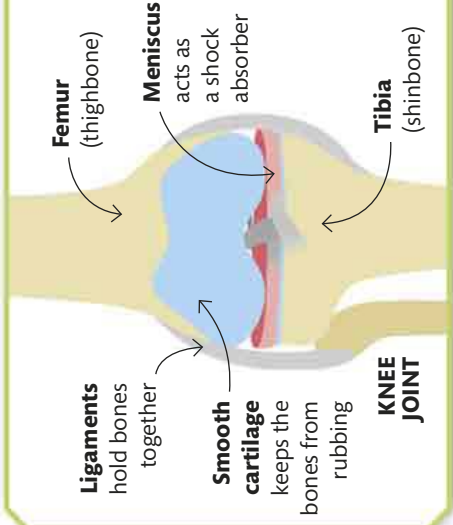
The seven angular, box-shaped ankle bones have little tilting motion. They can slide to and fro as well as sideways against each other.

“There are
150 joints
that cannot
move”



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 estrogen, 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

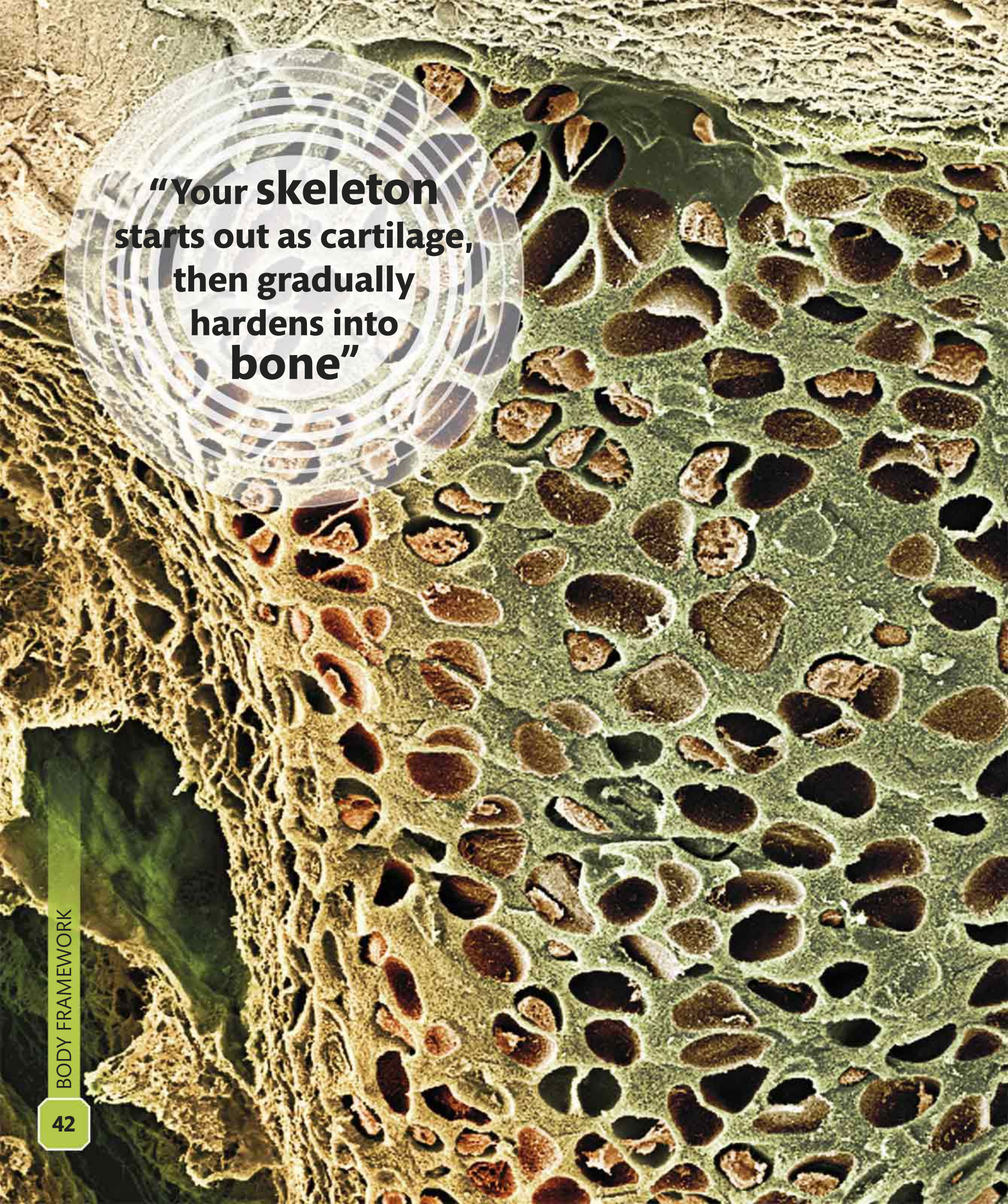


360°

Shoulder can rotate in two directions



“One person in 30 has extra-flexible joints”

A microscopic cross-section of bone tissue. The image shows a transition from a porous, fibrous structure on the left to a more organized, cellular structure on the right. The right side features numerous circular or oval-shaped osteons, each with a central canal. The overall color palette is a mix of light brown, tan, and greenish-yellow.

“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 keeps the ends of your bones from 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 squishy and slippery. It also forms various stiff-yet-flexible body parts, such as the nose and ear flaps.

STATS AND FACTS

QUALITY



Cartilage is
5–10 TIMES
more slippery than ice

BODY PERCENTAGES

Cartilage forms
1–2%
of the whole human body

Cartilage makes up
100%
of a shark's skeleton

COMPOSITION



Cartilage is up to
80%
water



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.



MUSCLE FIBERS

A muscle contains bundles of two kinds of fibers, each less than 1 mm wide and ¼–2 in (5–40 mm) long. Fast-twitch fibers shorten rapidly with great force but tire quickly.

Slow twitch-fibers contract gradually but keep going for longer.



Biceps bends elbow

Latissimus dorsi, the broadest muscle of back, pulls extended arms back to the side of the body

Gluteus maximus, a large muscle that extends the bent thigh

BUILT FOR SPEED

The biggest muscles are in the legs, and they hurl the body forward 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.

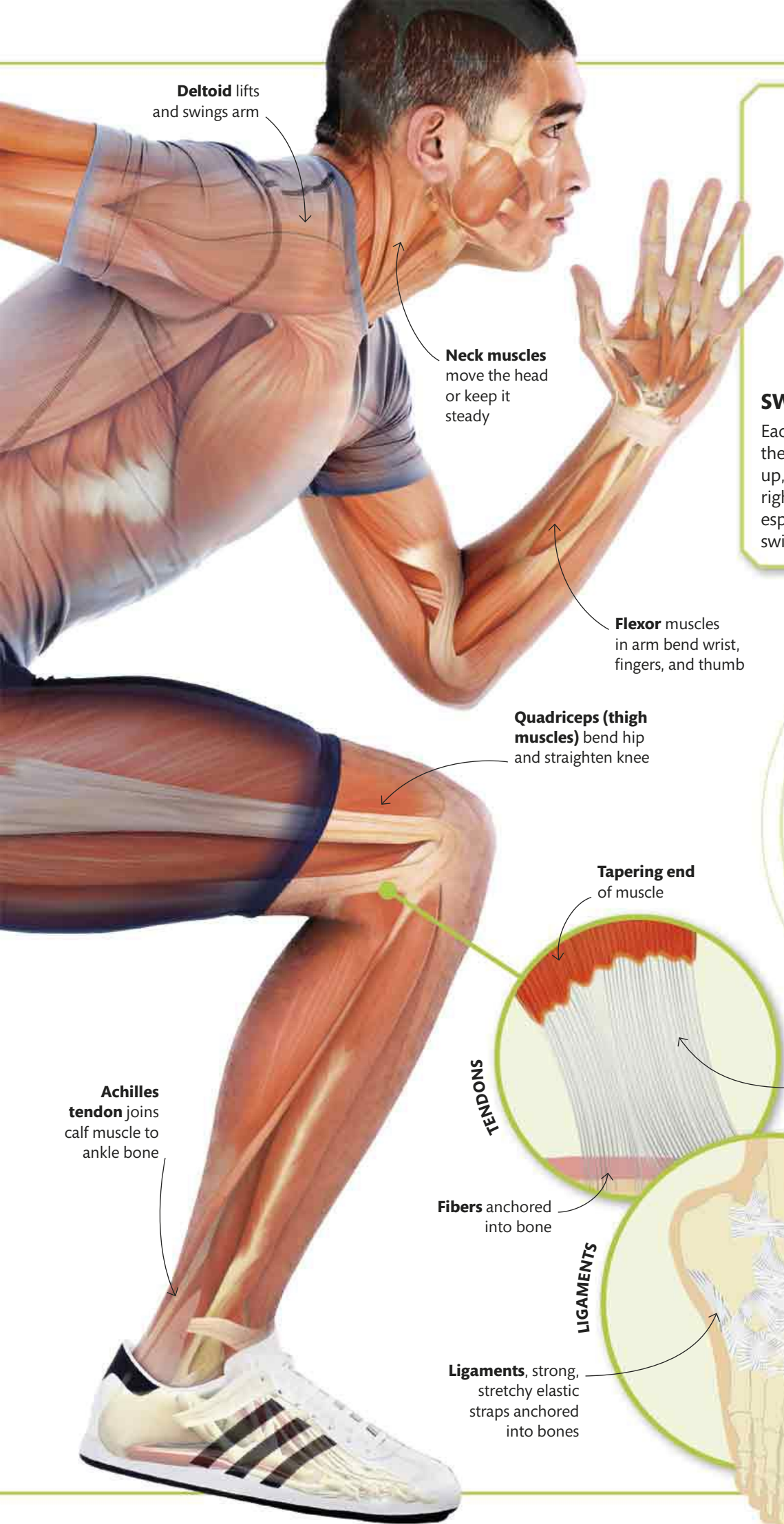
Hamstring muscles join rear thigh muscles to upper shin

Calf muscle bends knee and straightens ankle

Sartorius bends hip and knee and twists thigh. It is used when you sit in cross-legged position

Muscles on the front of the leg bend ankle upward

MUSCLES MAKE UP 40% OF YOUR BODY WEIGHT



Superior rectus muscle rotates the eye upward

Medial rectus muscle rotates the eye inward

SWING AND SWIVEL

Each eye is moved by six very thin, ribbonlike 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”

Tapering end of muscle

Tendon, with strong, rope-like fibers

Fibers anchored into bone

LIGAMENTS

Ligaments, strong, stretchy elastic straps anchored into bones

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% of the race”



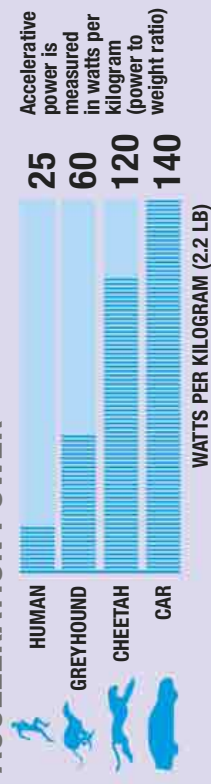
SUPER SPRINTER

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



SPRINTING SPEEDS



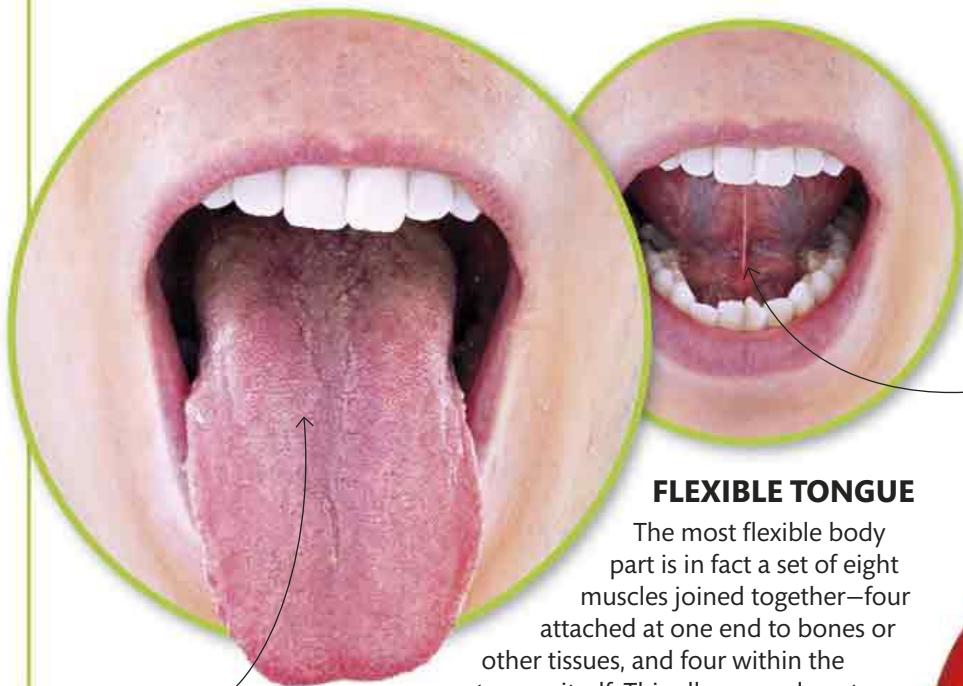
Dipping to the finish

This sprinter sweeps his arms back to reduce air resistance and leans his body forward to cross the line at the earliest possible 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 multicoordination.



Crosswise muscles poke tongue out

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.

**EXERCISE
MAKES MUSCLES
THICKER**

Superior, or surface muscles curl up tongue

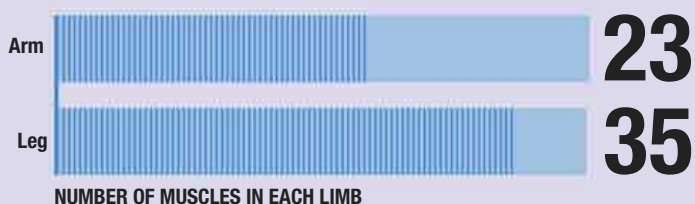
Extended leg with knee straightened



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

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

STATS AND FACTS



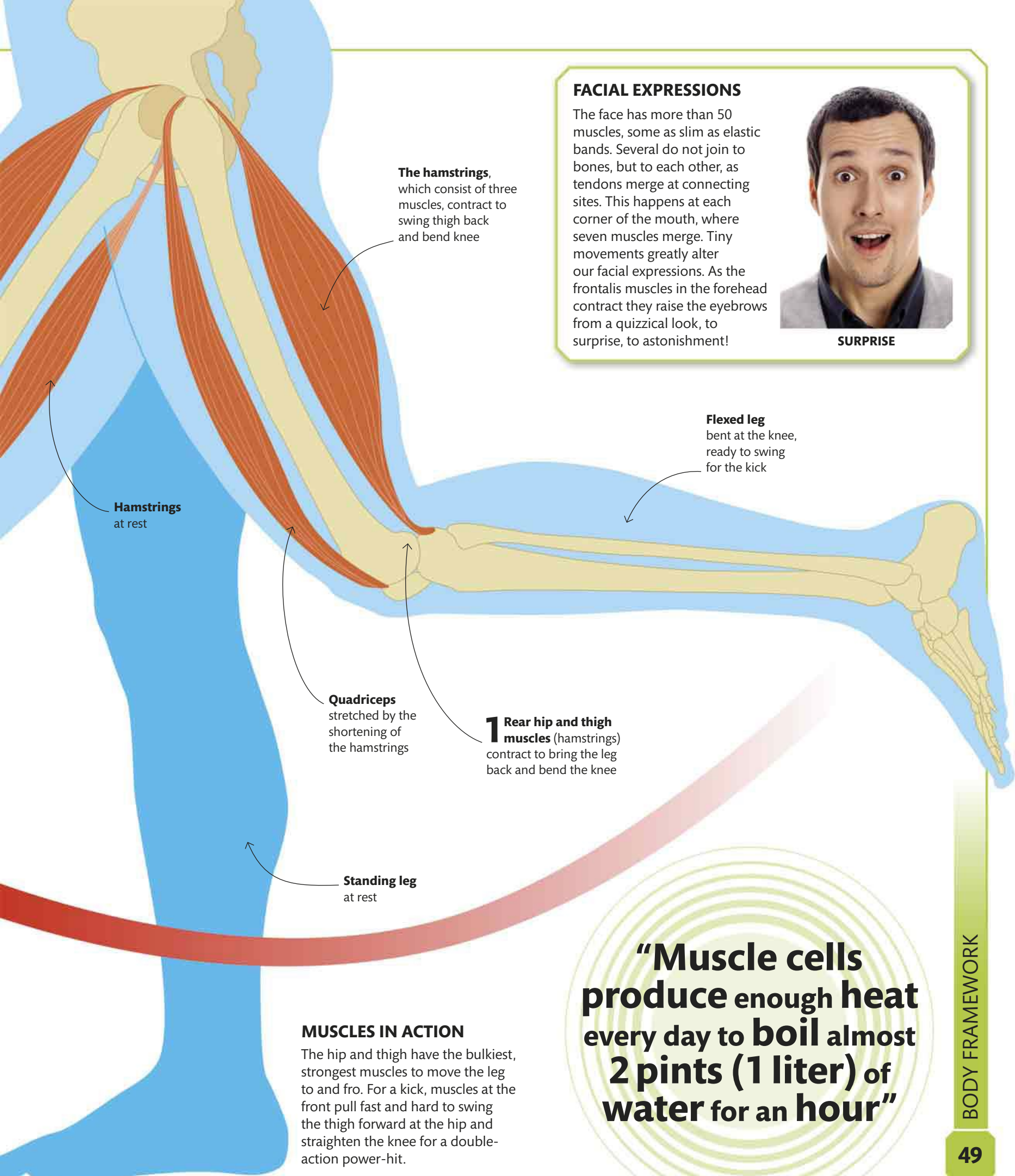
MUSCLE COORDINATION



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



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



The hamstrings, which consist of three muscles, contract to swing thigh back and bend knee

Hamstrings at rest

Quadriceps stretched by the shortening of the hamstrings

1 Rear hip and thigh muscles (hamstrings) contract to bring the leg back and bend the knee

Standing leg at rest

Flexed leg bent at the knee, ready to swing for the kick

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 forward at the hip and straighten the knee for a double-action power-hit.

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

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

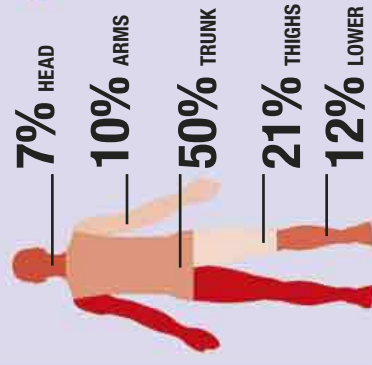
SUPER STRENGTH

Holding power

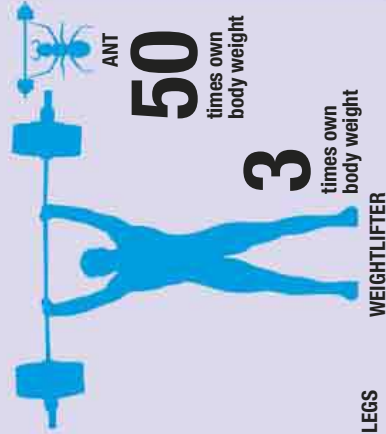
You don't need to move your muscles to make them work hard—simply tightening them can produce a huge amount of force. Holding a position requires raw strength. But attention to balance and posture is also important, because it prevents individual muscles from wasting energy by working against other muscles 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
22 tons”**



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.

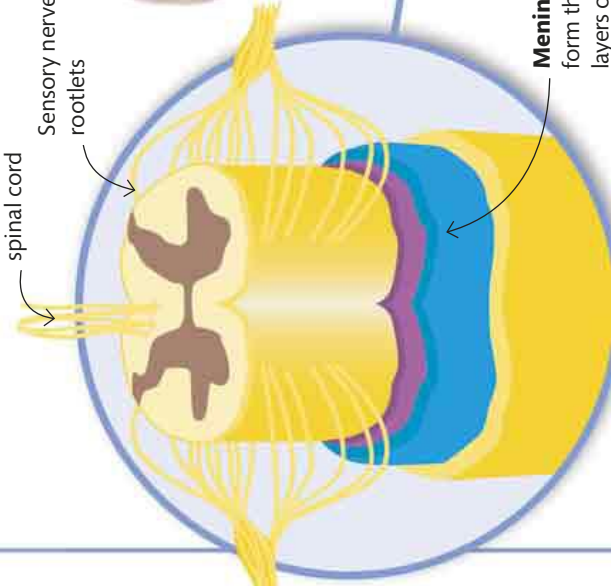
TOTAL INTRANET

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.

Nerve fibers run between brain and spinal cord

Sensory nerve rootlets



Meninges form three layers of protective covering

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 fibers. From it extend 31 pairs of spinal nerves to the chest, arms, lower body, and legs.

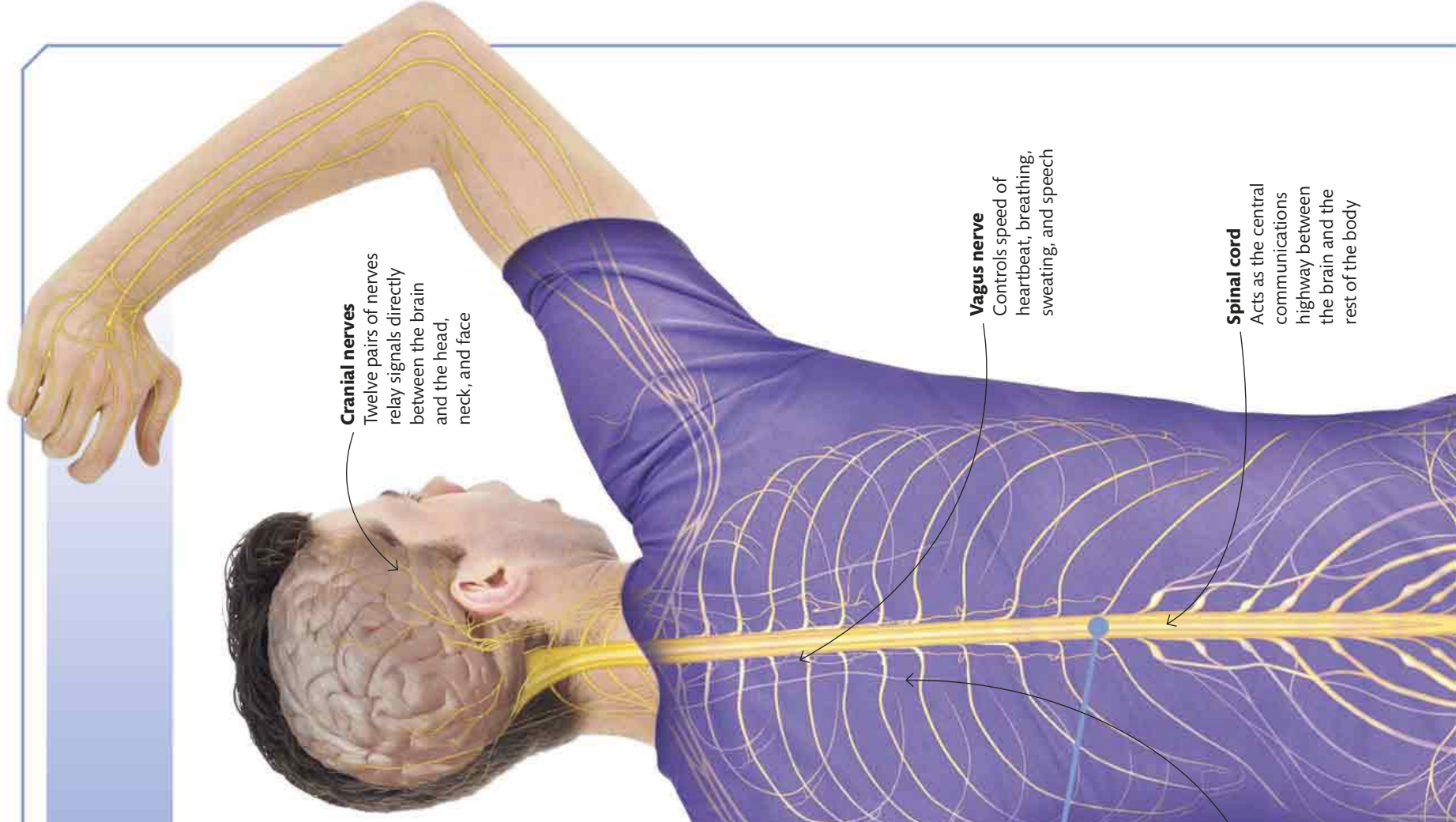
Cranial nerves
Twelve pairs of nerves relay signals directly between the brain and the head, neck, and face

Vagus nerve
Controls speed of heartbeat, breathing, sweating, and speech

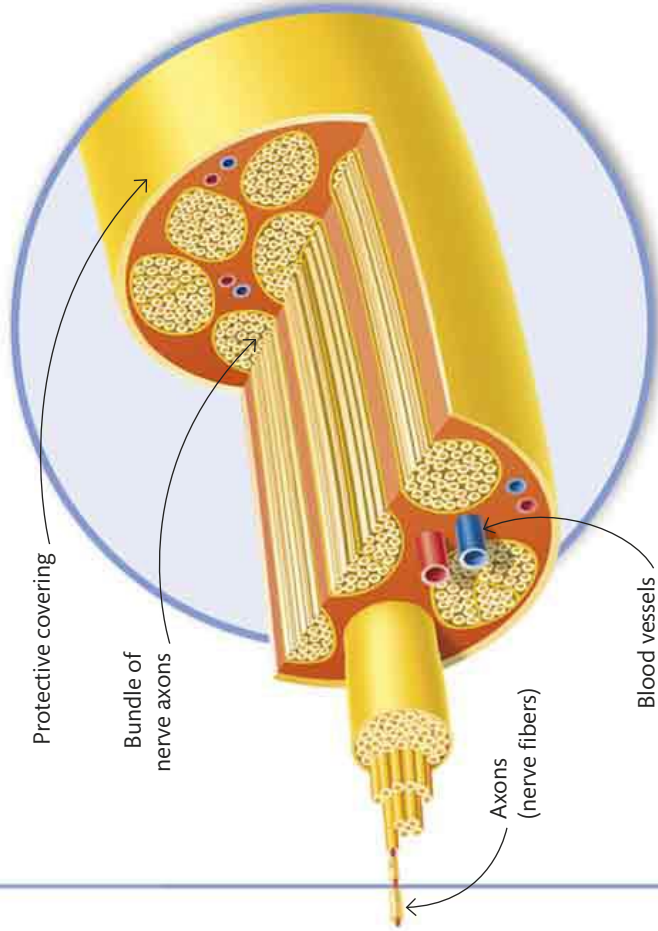
Spinal cord
Acts as the central communications highway between the brain and the rest of the body

Phrenic nerve
Carries messages to and from the diaphragm and can trigger hiccups

Ulnar nerve
A blow to the elbow produces a tingling effect in your "funny bone"



Adult brains lose 100,000 neurons per day

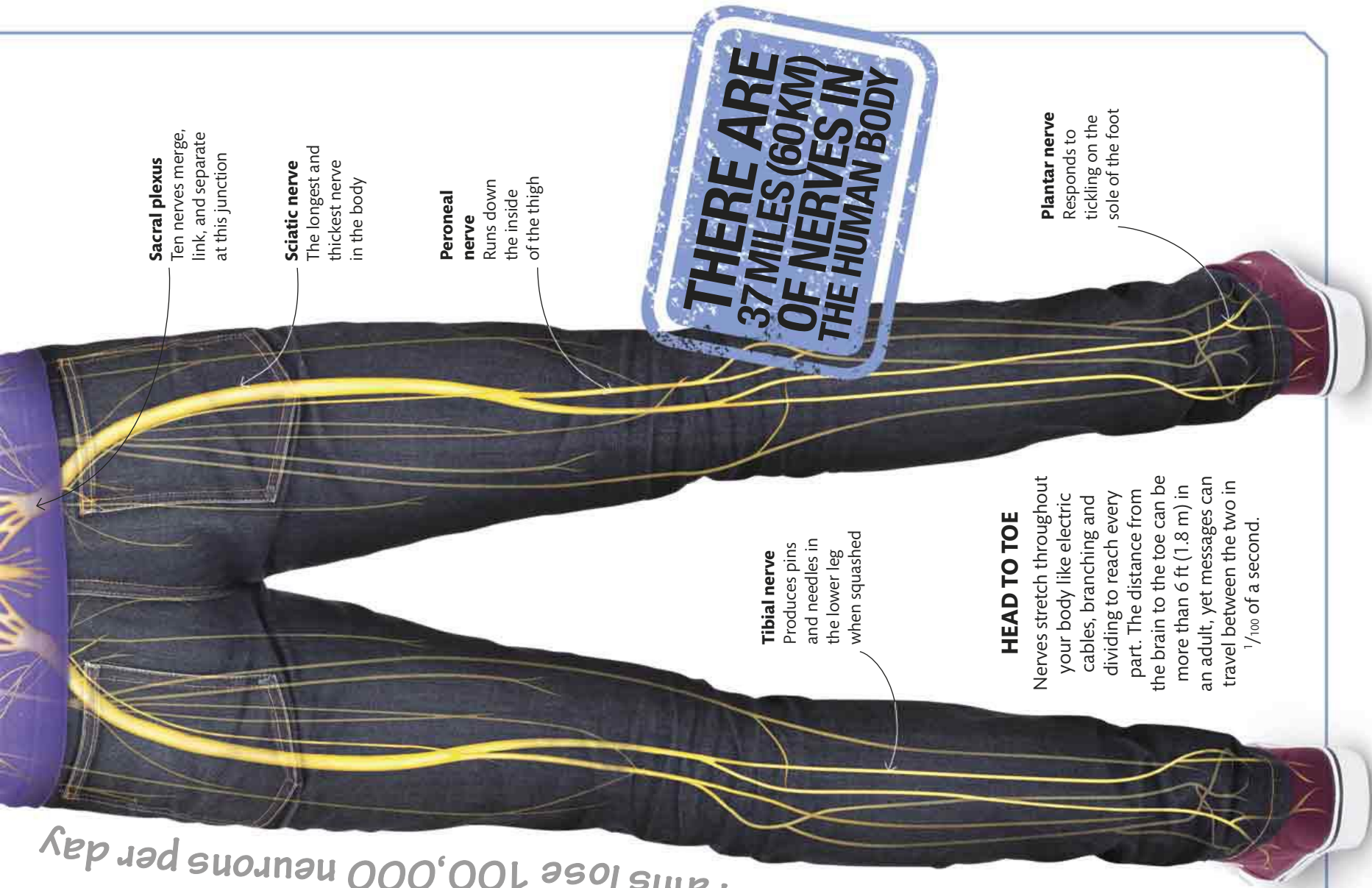


WHAT A NERVE!

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

STATS AND FACTS

AVERAGE LENGTH OF SPINAL CORD



Sacral plexus
Ten nerves merge, link, and separate at this junction

Sciatic nerve
The longest and thickest nerve in the body

Peroneal nerve
Runs down the inside of the thigh

Tibial nerve
Produces pins and needles in the lower leg when squashed

HEAD TO TOE

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

Plantar nerve
Responds to tickling on the sole of the foot

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

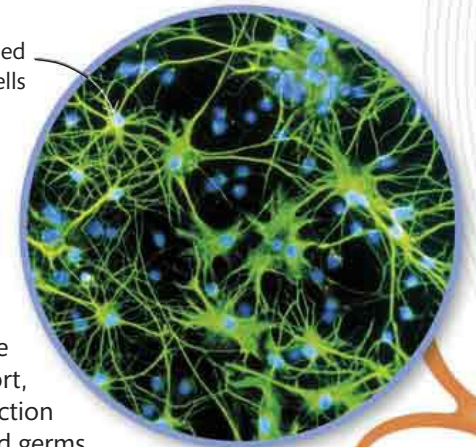
Maximum time the brain can concentrate on something before losing efficiency

INSIDE THE MEGAWEB

Nerves and nerve cells

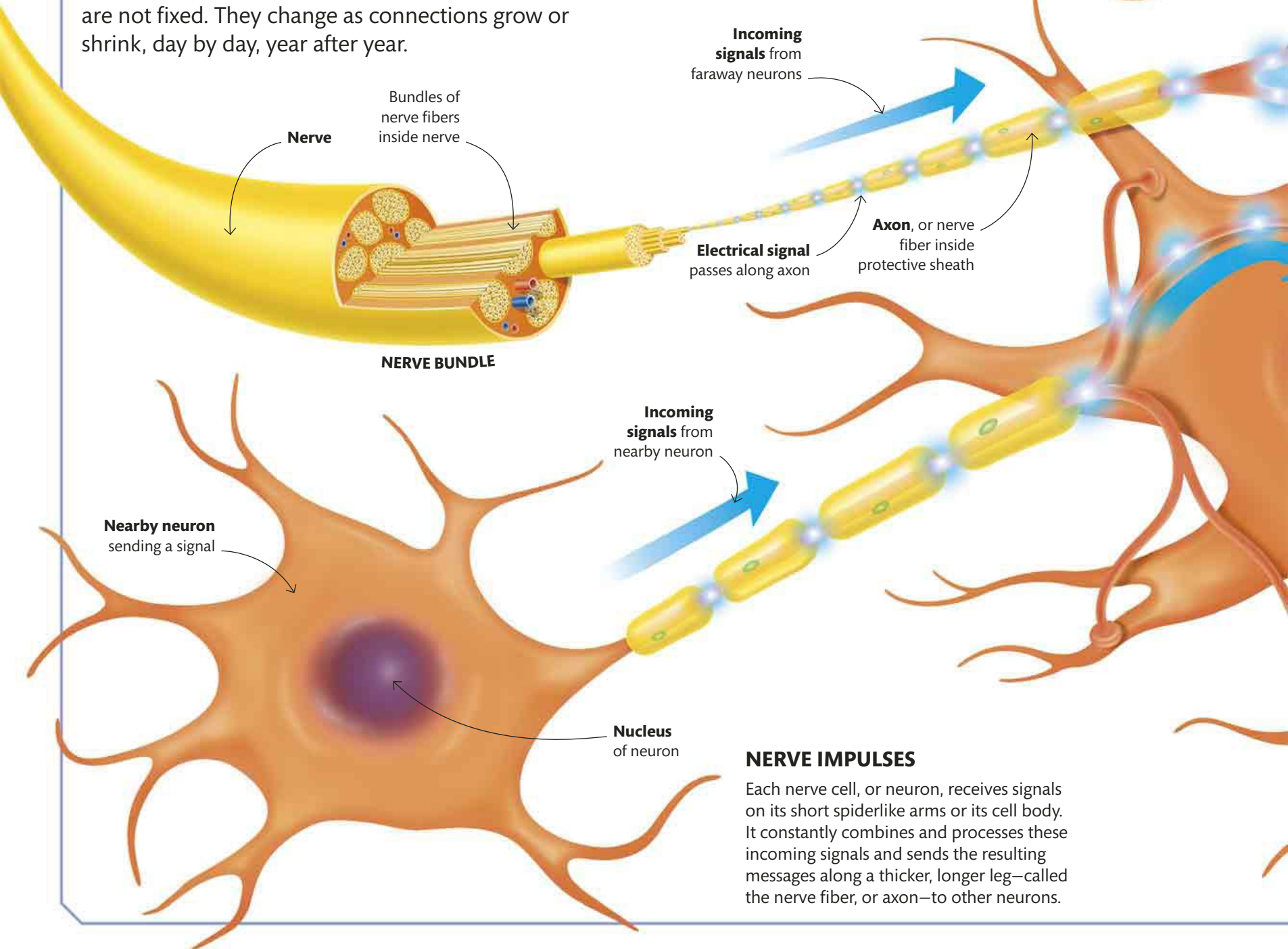
Take apart the nerve system, bit by bit, and you reach its smallest parts—nerve cells, or neurons. They are among the most specialized and long-lasting of all cells. Their job is to receive, process, and send on nerve messages, in the form of tiny pulses of electricity. Each neuron has a complex weblike 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.

Star-shaped glial cells



LITTLE HELPERS

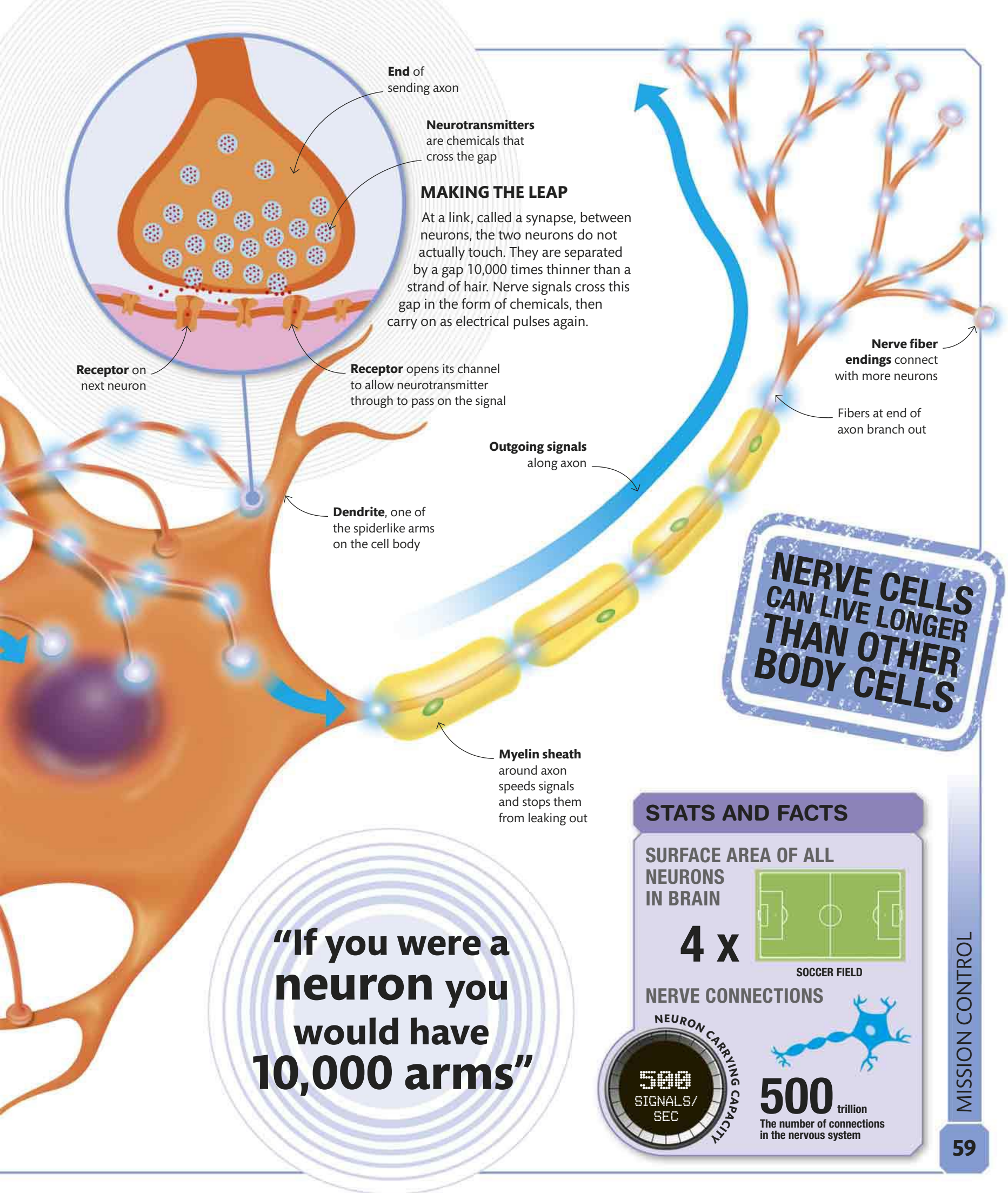
In the entire nerve system, fewer than half the cells are neurons. The rest—called glial cells—give neurons physical support, nutrients, and protection from damage and germs.



NERVE BUNDLE

NERVE IMPULSES

Each nerve cell, or neuron, receives signals on its short spiderlike 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 fiber, or axon—to other neurons.



End of sending axon

Neurotransmitters are chemicals that cross the gap

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.

Receptor on next neuron

Receptor opens its channel to allow neurotransmitter through to pass on the signal

Dendrite, one of the spiderlike arms on the cell body

Outgoing signals along axon

Myelin sheath around axon speeds signals and stops them from leaking out

Nerve fiber endings connect with more neurons

Fibers at end of axon branch out

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 FIELD

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 multishaped 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 multibranching 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.

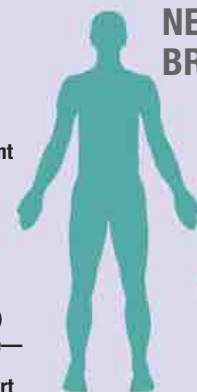
STATS AND FACTS

VAST NETWORK



620 miles
(1,000 km) All nerve cell bodies lined up end to end—equivalent to the distance from London to Berlin

NEURONS IN BRAIN'S CORTEX



20 billion

LONGEST NERVES



3 ft (1 m)
Sciatic nerve
HUMAN



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



21 million
RAT

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. Because 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"

Cerebrum
is folded to fit inside the skull

Corpus callosum
is a bundle of nerve fibers that links the two halves of the brain

Thalamus
relays nerve signals to the cerebrum

Hypothalamus
controls temperature, hunger, and many automatic processes

Pituitary gland
regulates hormones

Brain stem
connects the spinal cord with the brain

Cerebellum
is responsible for balance and posture

AT A GLANCE



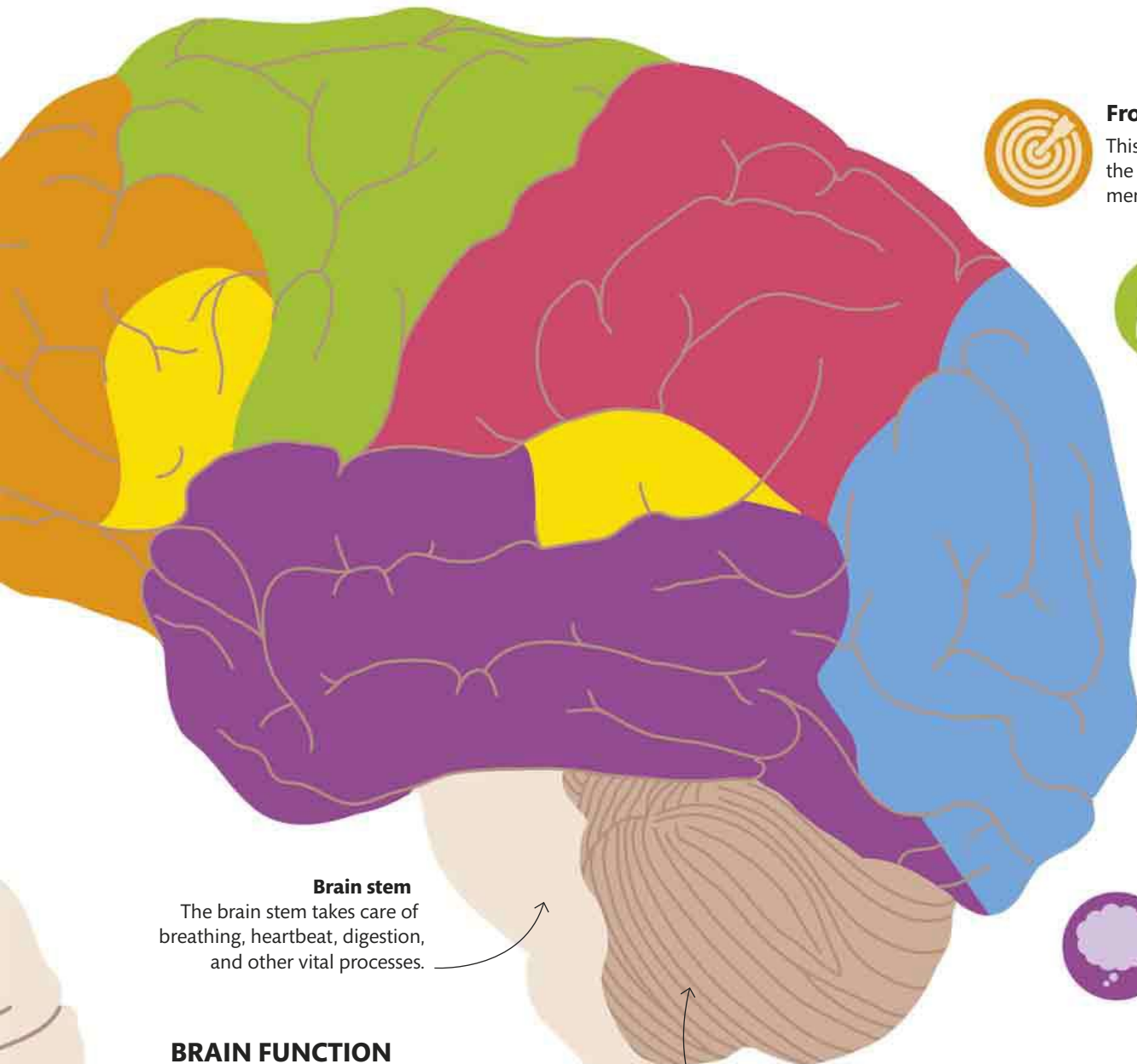
■ **SIZE** Average adult brain: weight 3 lb (1.4 kg); width 6 in (14 cm); length 7 in (17 cm); height 4 in (9.5 cm)

■ **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.

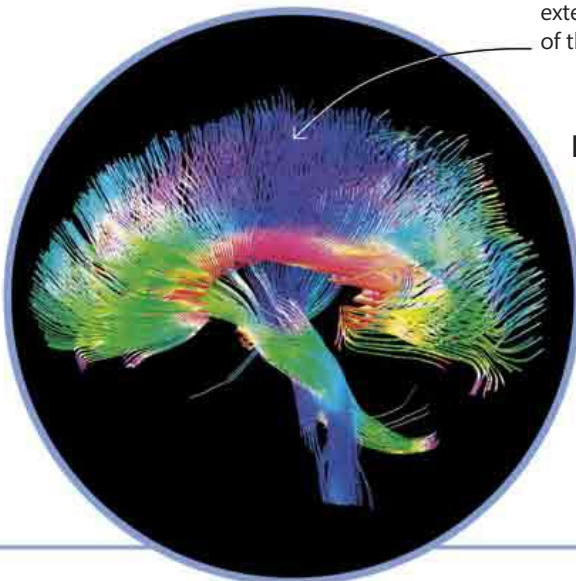
Cerebellum

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 fibers 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



10 lb
(4,500 g)



3 lb
(1,400 g)



1 oz
(30 g)



20%
of body energy is used up by the brain



2%
of body weight is made up by the brain

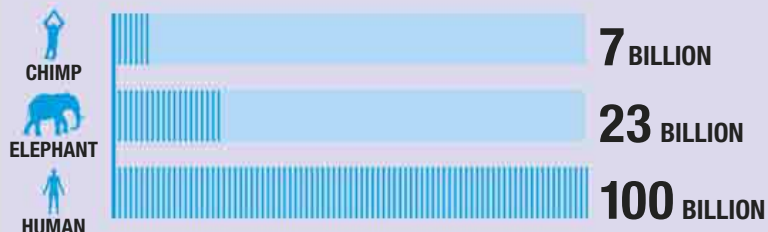
LIVING DANGEROUSLY

The teen brain

On the outside, the brain looks similar all through life. But its trillions of microconnections 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

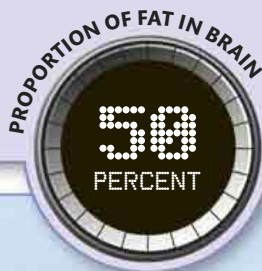
NEURONS IN THE BRAIN



LIGHTBULB MOMENT

10–20 WATTS

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



Defying gravity

Suspended in midair, arms thrown to his side, this young stunt biker throws caution to the winds. 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

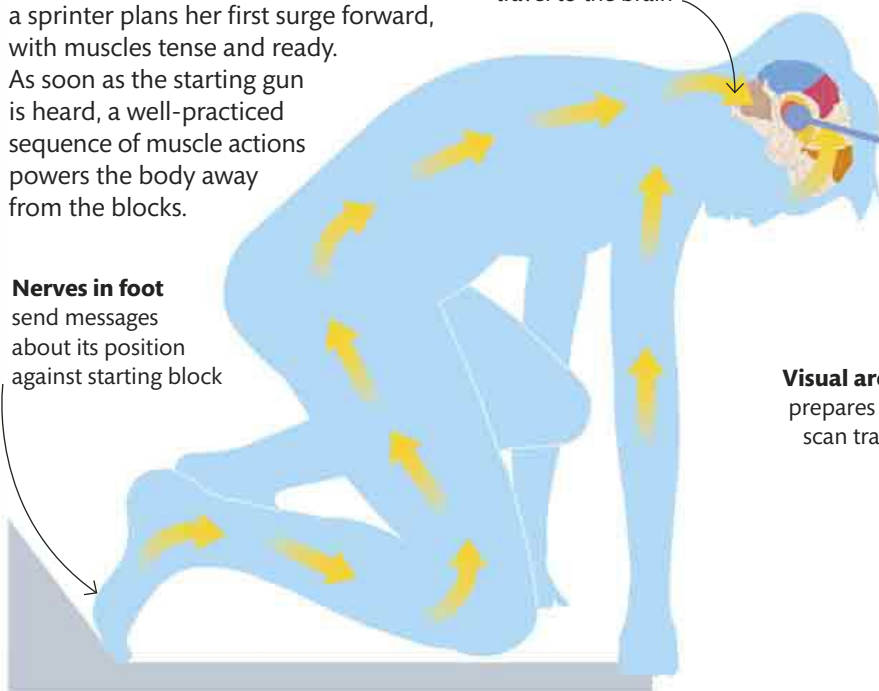
Some body movements, such as heartbeats and breathing, happen day and night. These internal actions are mostly involuntary, or controlled by automatic parts of the brain, so the conscious mind does not need to think about them. Voluntary movements are controlled by the conscious mind's decisions. Their 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.

ON YOUR MARK, GET SET, GO!

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

Nerves in foot send messages about its position against starting block

Nerve messages travel to the brain



CONCENTRATION

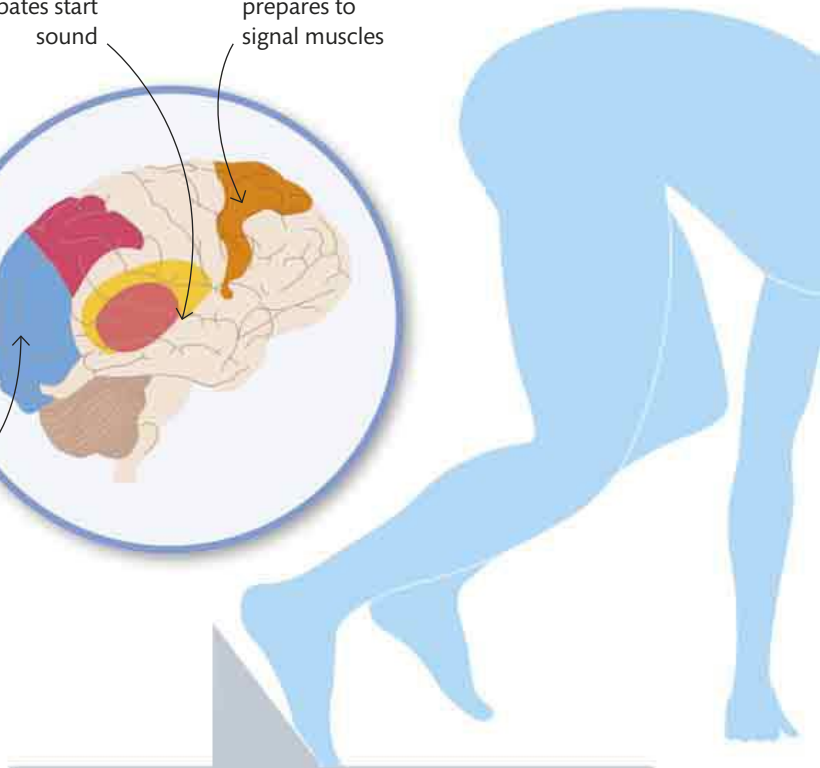
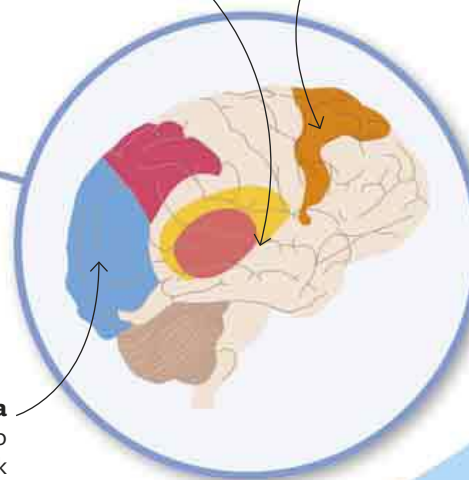
The brain's awareness can focus entirely on one movement or motor task, such as playing an instrument. Closing the eyes shuts off sight, and various brain parts, such as the thalamus, filter out other unwanted nerve signals.



Hearing area anticipates start sound

Front cortex prepares to signal muscles

Visual area prepares to scan track



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 to partly 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

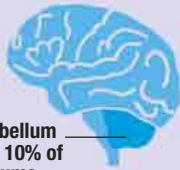
STATS AND FACTS



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

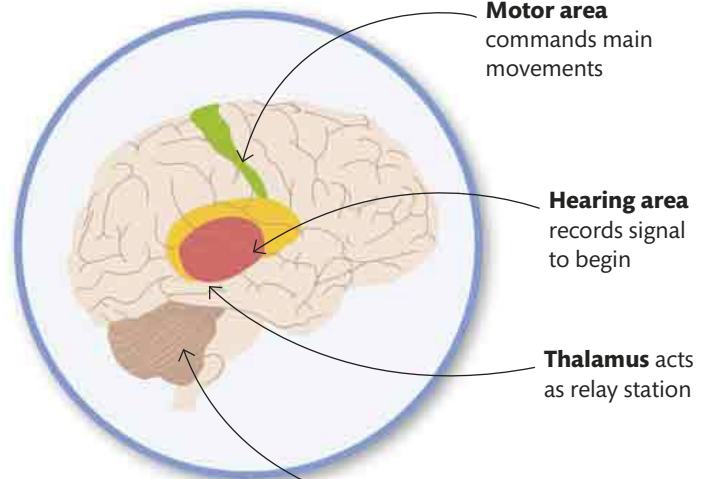
0.1
seconds

The shortest time between hearing starting gun and leaving block



The cerebellum takes up 10% of brain volume

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



Motor area
commands main movements

Hearing area
records signal to begin

Thalamus acts as relay station

Cerebellum organizes details of action

Premotor area
prepares rehearsed action

Thalamus
communicates with motor areas

Messages from brain travel down spine to activate muscles

A million signals move a finger in a second

Leg and arm muscles suddenly pull hard

THE CEREBELLUM HAS 85 BILLION NEURONS

GO

Leg muscles push hard to drive the body forward, 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 fiber has a motor end plate where the electrical nerve signals pass into muscle fibers (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 at least one-twentieth of a second, while nerve messages from brain to foot muscles may take almost one-thirtieth of a second.

“Reaction times become slower with a lack of sleep”

STATS AND FACTS

REACTION TIMES



Fastest punch, start to finish
0.2 sec

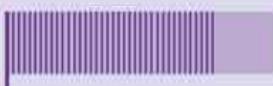


Kick reaction speed
115 ft/sec
(over 78 mph)

RESPONSE TO STIMULUS



SOUND



0.14 sec

80%

Improved reaction time after practice



SIGHT



0.18 sec





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 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”

Signals arrive at spinal cord

Brain not aware of problem yet

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.

Pain signals travel along nerve in arm

Skin sensors detect too much heat

Candle flame

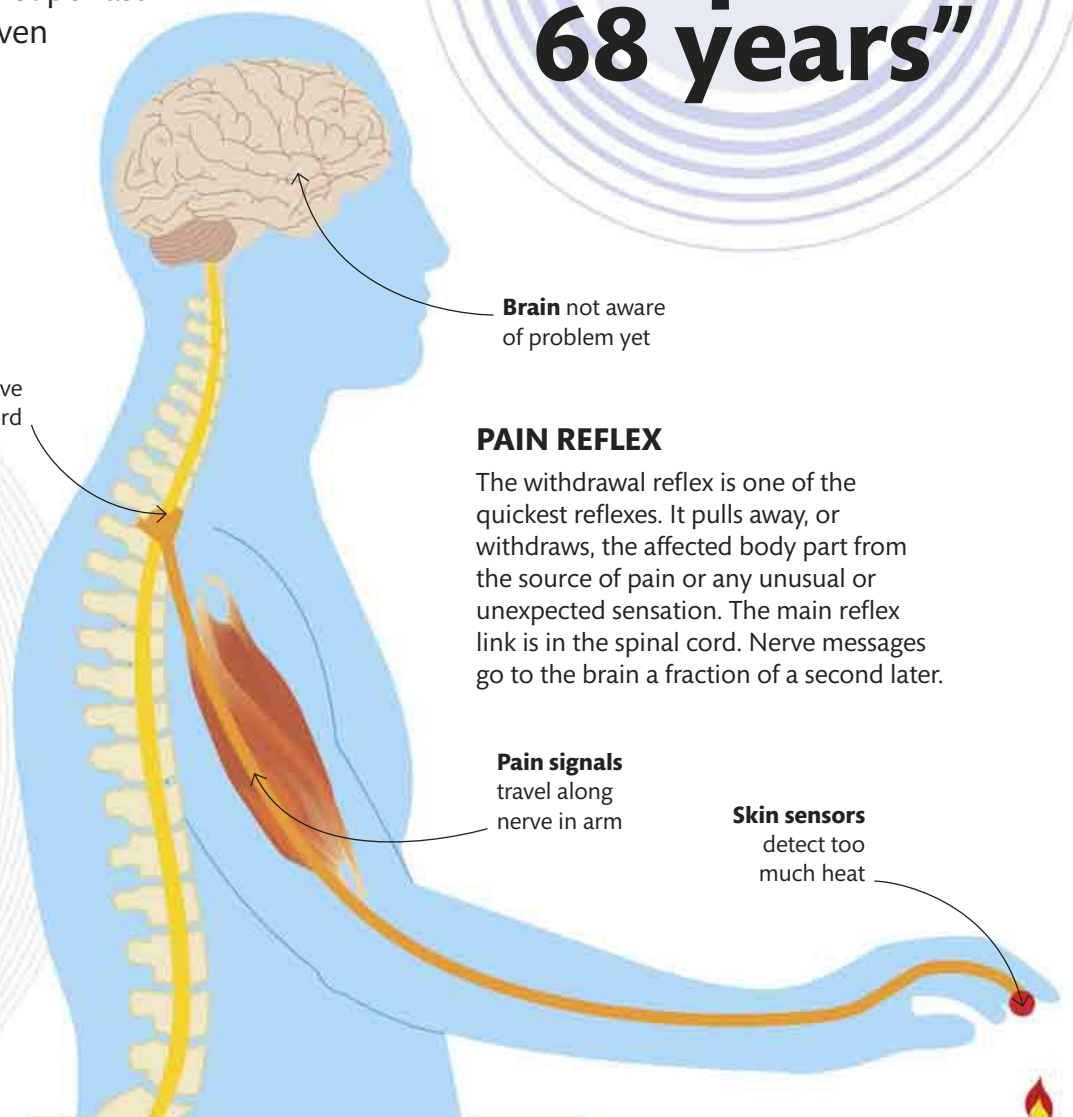


BORED? TIRED? YAWN...

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.

1 Danger threatens

Too much heat, cold, pressure, or other discomfort could damage the body. So, when you unknowingly reach out toward a flame, skin sensors detect it and fire nerve signals along nerve fibers 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

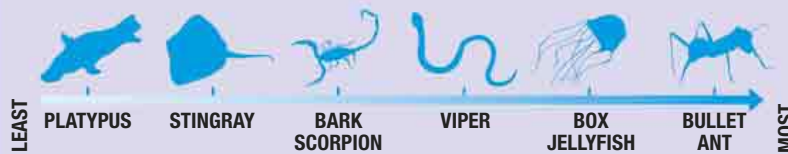
Healthy reflexes show the nerve system is working well, so they are regularly tested at medical check-ups. The pupil reflex is the busiest. As the eye looks around at light and dark areas, a reflex link to the iris muscles (colored part) continuously adjusts the size of the pupil (hole), to keep the 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.



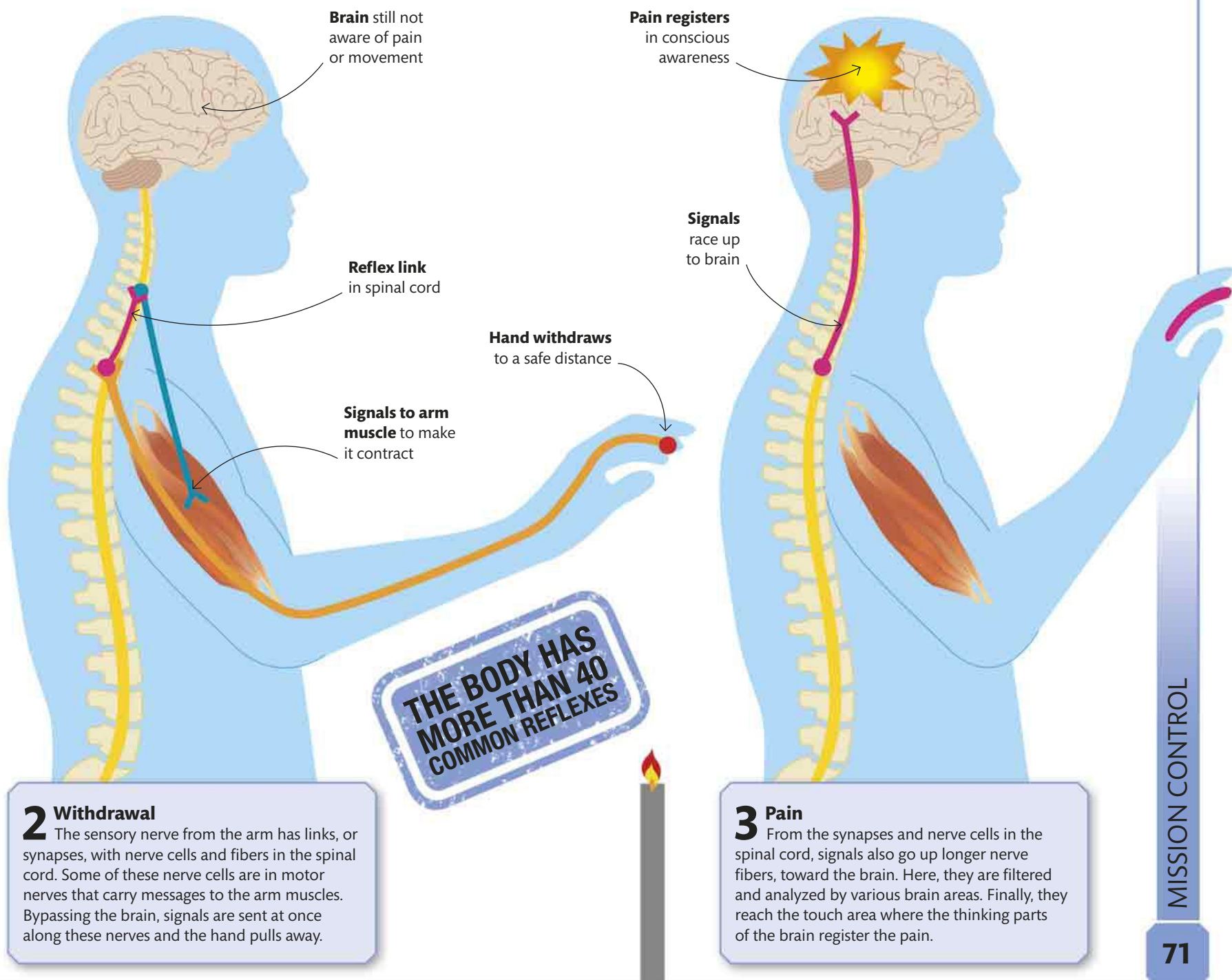
PUPIL WIDE OPEN

STATS AND FACTS

MOST PAINFUL BITES AND STINGS



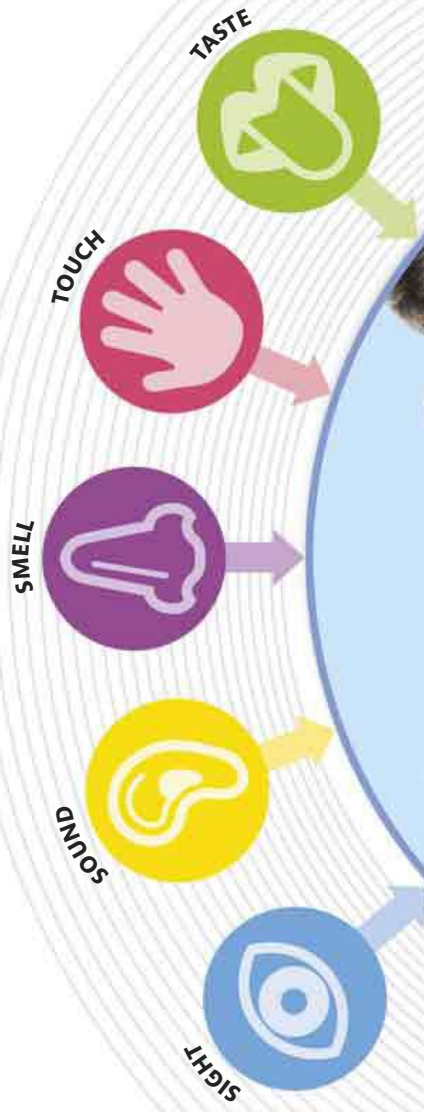
PAIN SCALE



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.



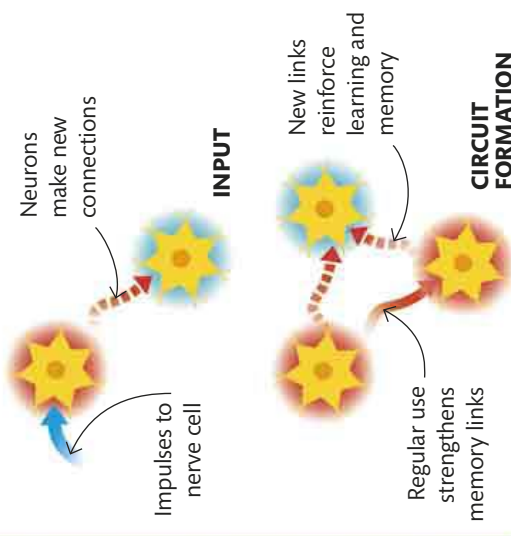
MEMORY INPUTS

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 color. For events such as vacations, memories retain a whole range of sights, sounds and other sensations. All five senses can feed a memory.

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

HOW MEMORIES ARE FORMED

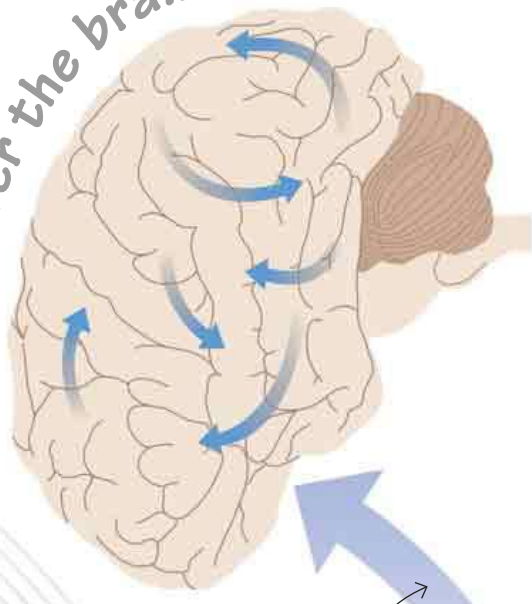
A memory is a new set of connections, or synapses, between neurons. Over time, as nerve signals pass between the neurons, they set up fresh connections. The more the pathways are used, the more established the memories become. If not recalled occasionally, they are forgotten as the connections weaken.



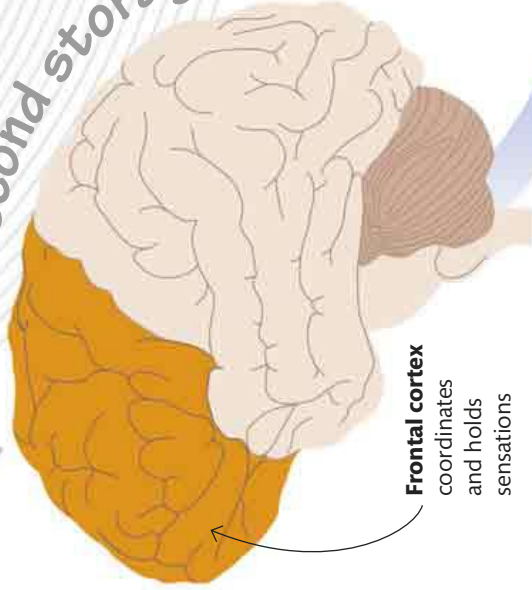
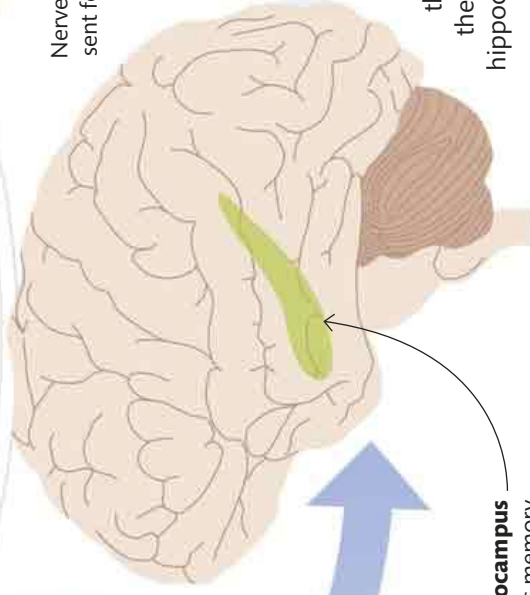
Links all over the brain

SHORT-TERM MEMORY HOLDS 7 ITEMS

20-second storage



Nerve patterns are sent for long-term storage



Frontal cortex
coordinates and holds sensations

SHORT-TERM MEMORY

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

Hippocampus
forms memory patterns

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 colors 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 becomes 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

“The longest a person has gone without sleep is 449 hours”

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.

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 odors, 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.

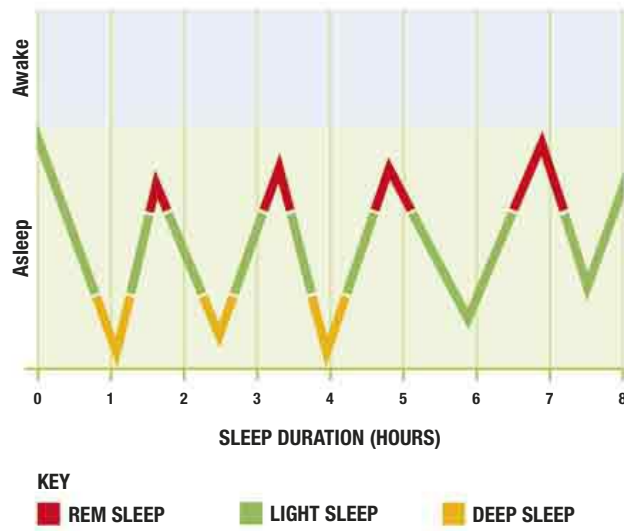


Digestive system

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 throughout. 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

Muscles

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



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.

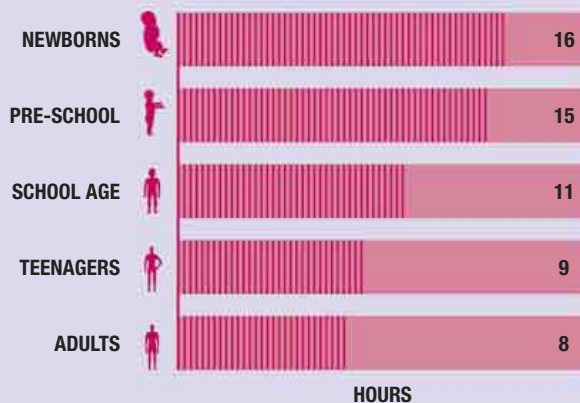


Bladder

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!

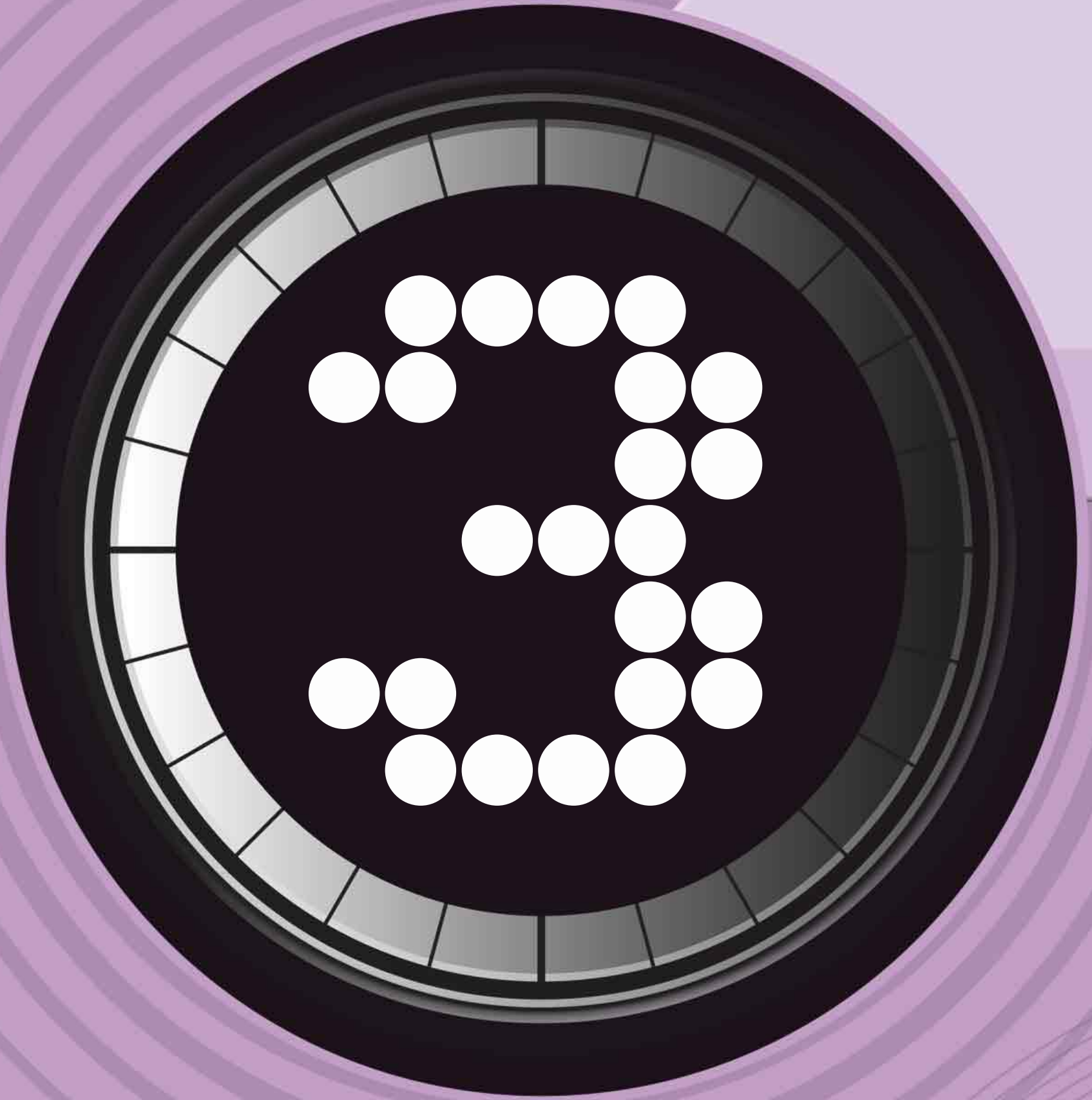
STATS AND FACTS

TIME SPENT SLEEPING



CAT

20 HOURS



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-color, 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 humor—a glassy, jellylike 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 jellylike vitreous humor keeps the eye ball-shaped.

Sclera forms the tough outer layer, or white, of the eye

Conjunctiva is thin, sensitive, and covers the white of the eye

Cornea is dome-shaped to bend light rays

Iris contains muscles, and pigments that give the eye color

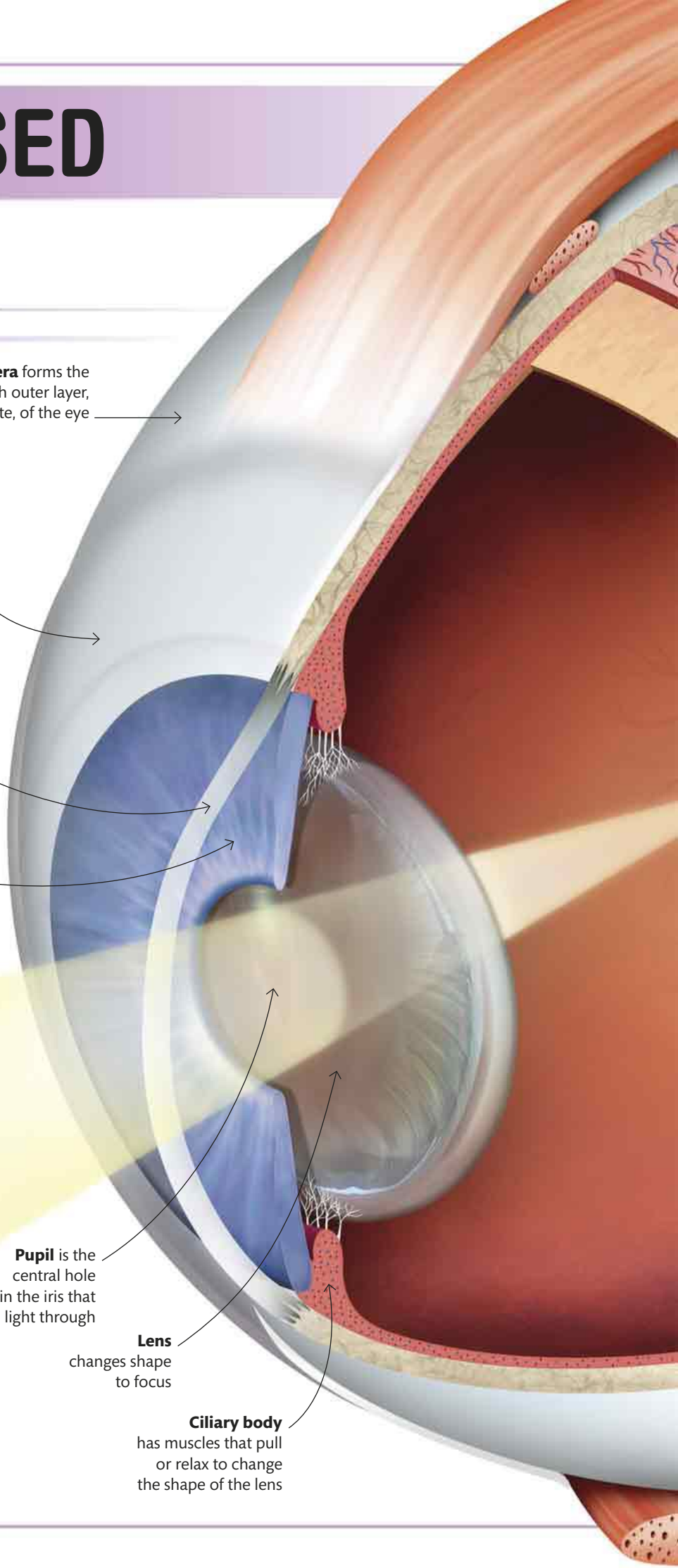
Pupil is the central hole in the iris that lets light through

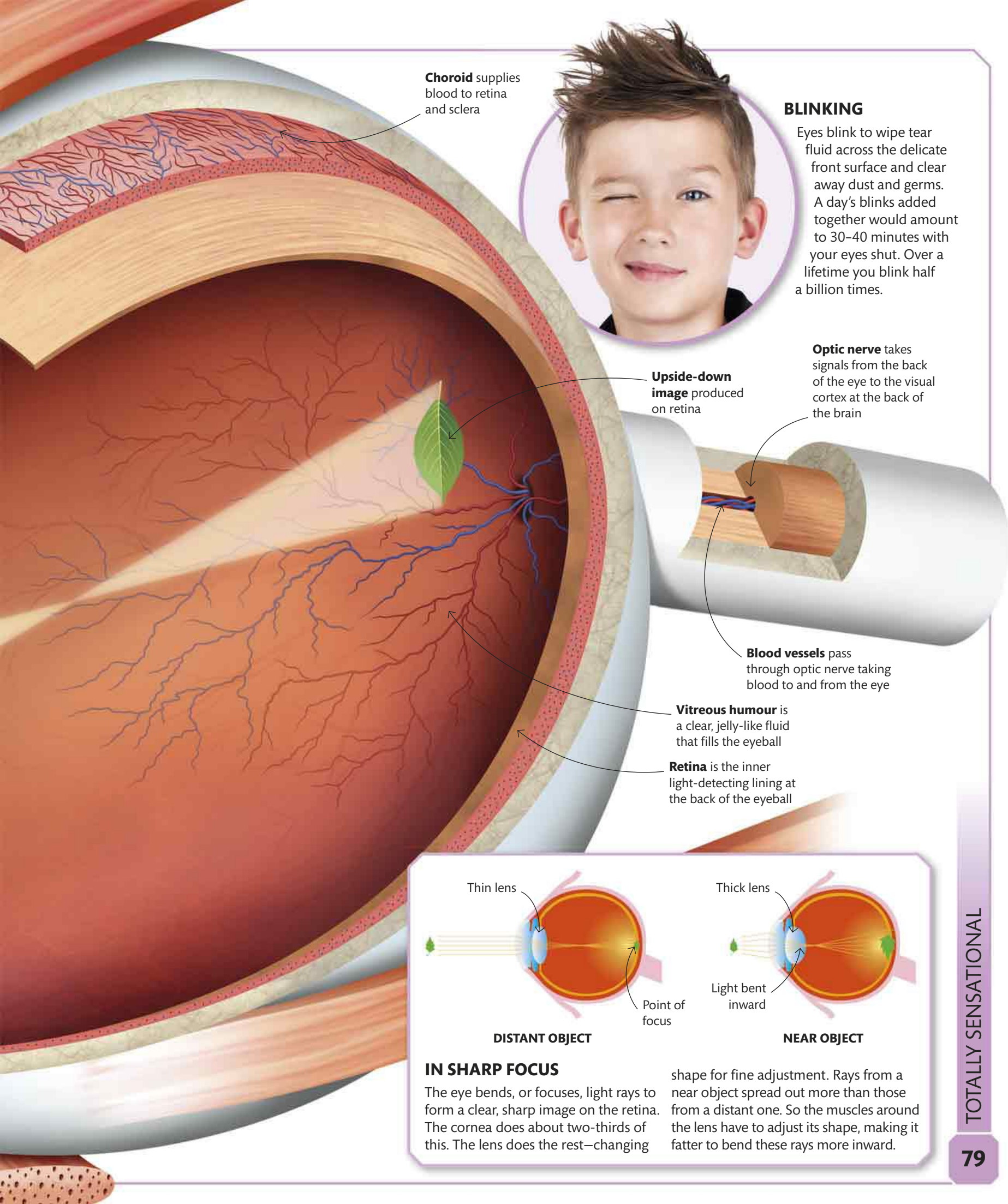
Lens changes shape to focus

Ciliary body has muscles that pull or relax to change the shape of the lens

Object reflecting light rays

YOU CAN BLINK 5 TIMES IN A SECOND





Choroid supplies blood to retina and sclera

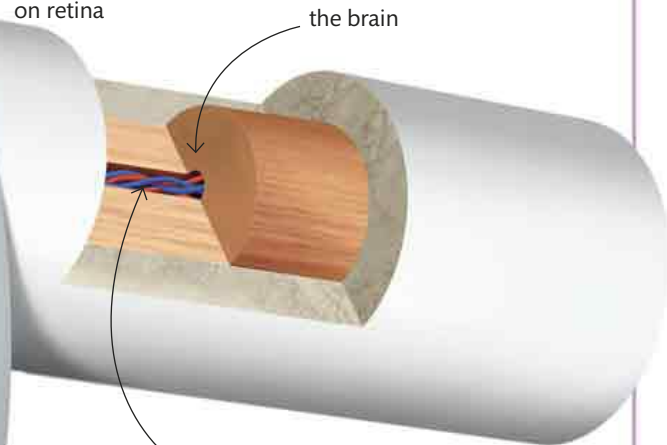
BLINKING

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.



Upside-down image produced on retina

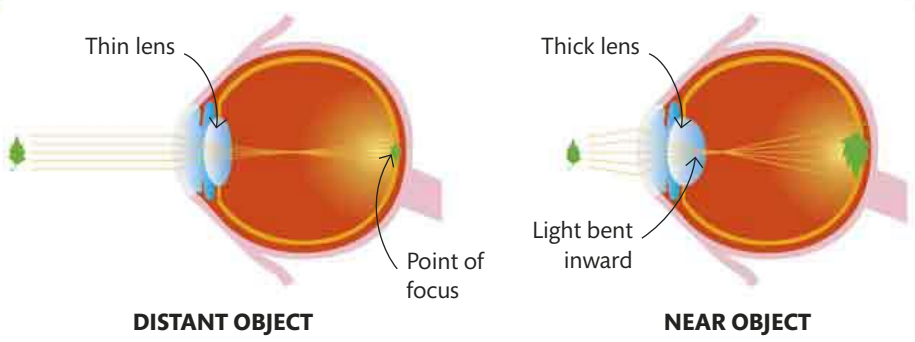
Optic nerve takes signals from the back of the eye to the visual cortex at the back of the brain



Blood vessels pass through optic nerve taking blood to and from the eye

Vitreous humour is a clear, jelly-like fluid that fills the eyeball

Retina is the inner light-detecting lining at the back of the eyeball



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 more inward.



Lining up the target

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

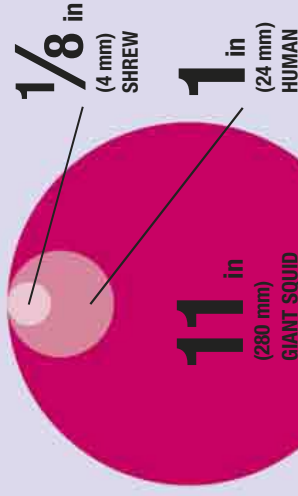
HAWKEYE

On target

The **human eye** is incredibly sensitive. In perfect darkness, it can detect a candle flame more than 6 miles (10 km) away! But such conditions are rare, because of light from the Moon, buildings, vehicles, and streetlights. 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

29
EYE GROWTH AFTER BIRTH
PERCENT

“The bullseye of an archery target is only 5 in (122 mm) in diameter”

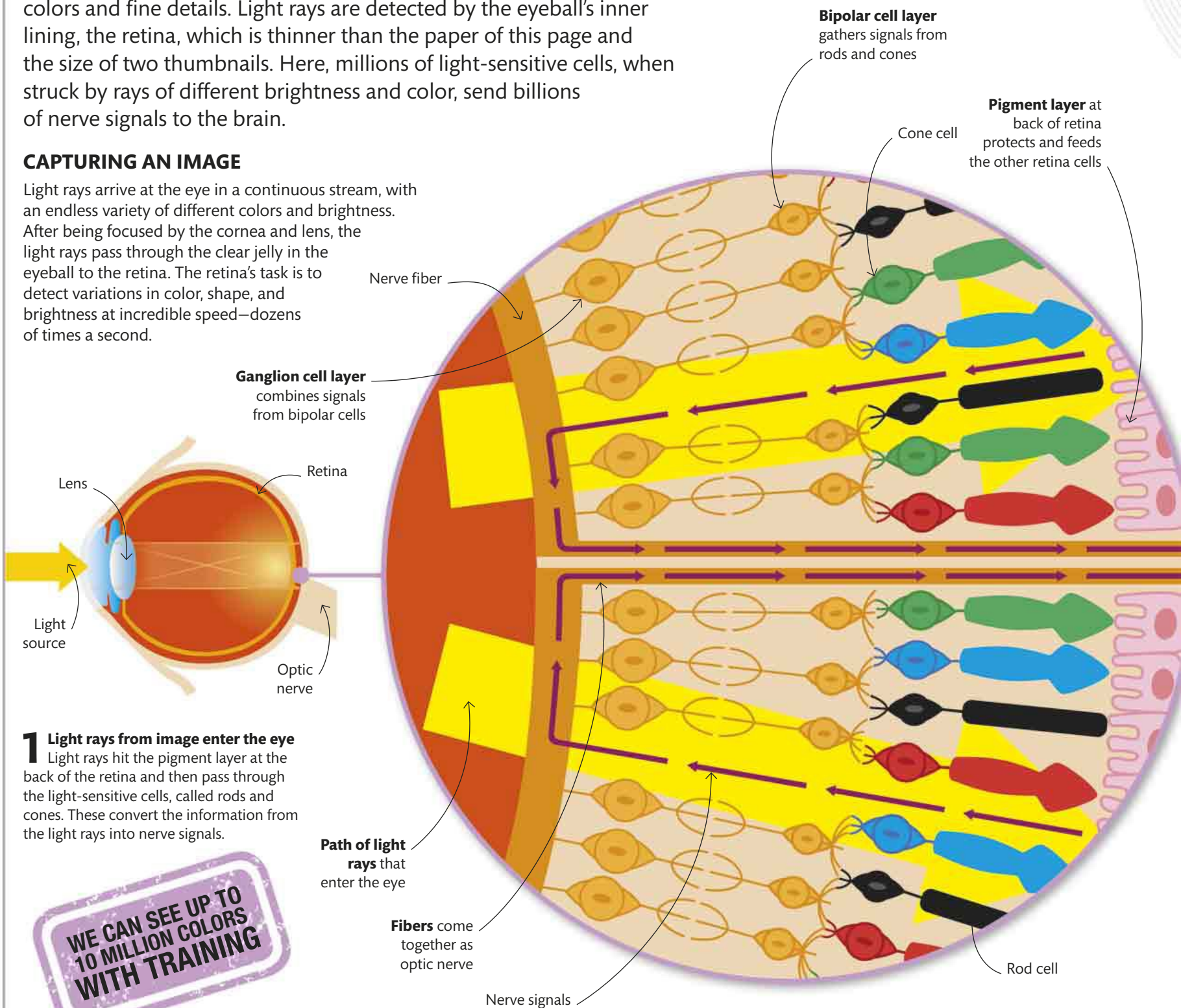
SEEING THE LIGHT

Fine detail and color

The human eye is one of the best of all mammal eyes at seeing colors 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 color, send billions of nerve signals to the brain.

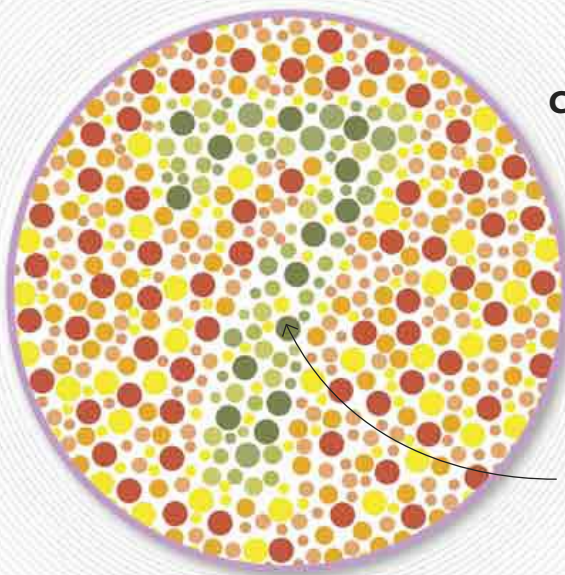
CAPTURING AN IMAGE

Light rays arrive at the eye in a continuous stream, with an endless variety of different colors 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 color, shape, and brightness at incredible speed—dozens of times a 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 COLORS WITH TRAINING



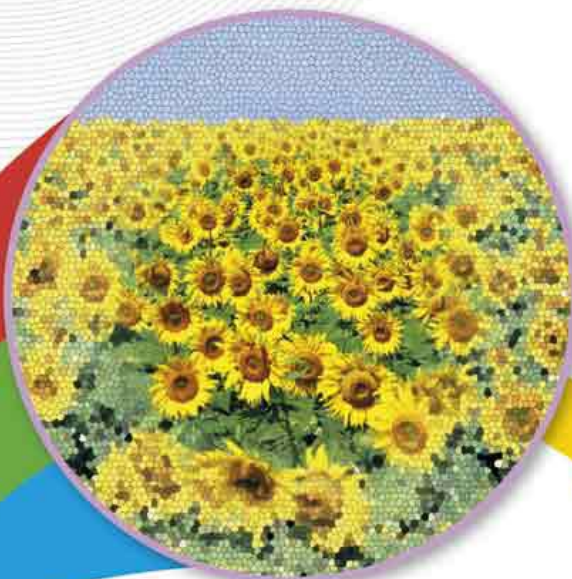
COLOR VISION PROBLEMS

Can you see a number here? Most eyes can see 2-5 million different colors and hues. But others do not see the normal range of colors, 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.

Color test

Those with red-green color blindness will not be able to distinguish the number in green from the red dots around it.

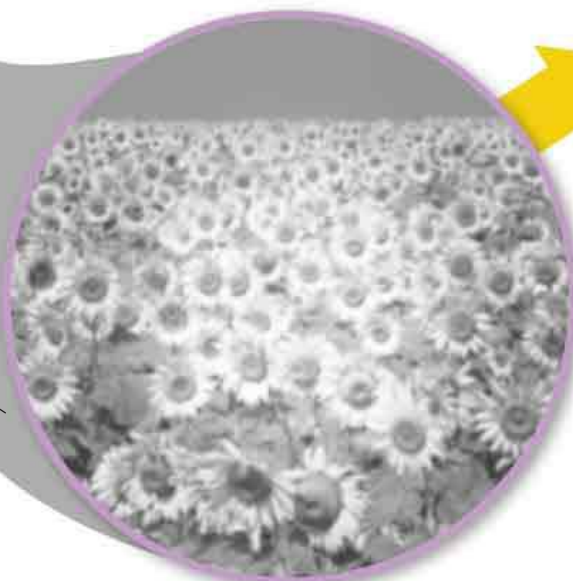
Three types of cone cell provide detailed color information about the central part of the image



2 Cones and rods

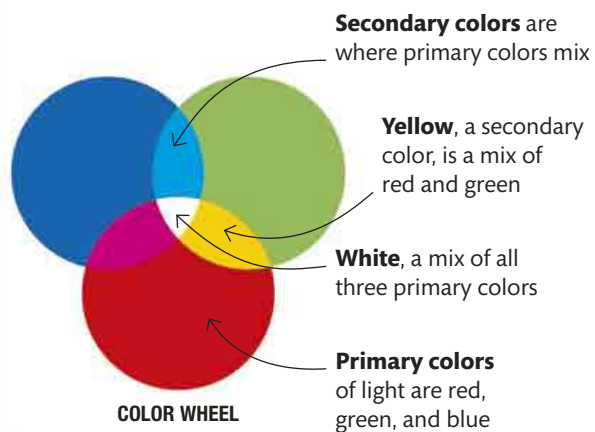
Cone cells are most numerous in a small patch of the retina, the fovea. They need bright light to detect fine details and colors. Rod cells occur over most of the retina. They work well in dim light, but do not see colors.

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



MIXING COLOR

There are three types of cone cell in our eyes that are sensitive to red light, green light, or blue light. Colors mix to produce a variety of different colors; 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.



Final image in color with greatest detail at center

3 In the mind's eye

The detailed color information given by the closely packed cones and the broader information, in shades of gray, from the rods is gathered by bipolar cells. Ganglion cells then combine the signals from the bipolar cells and transmit them through the optic nerve to the brain, to give a full-color, overall 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 color 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




NUMBER OF CONE CELLS



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.

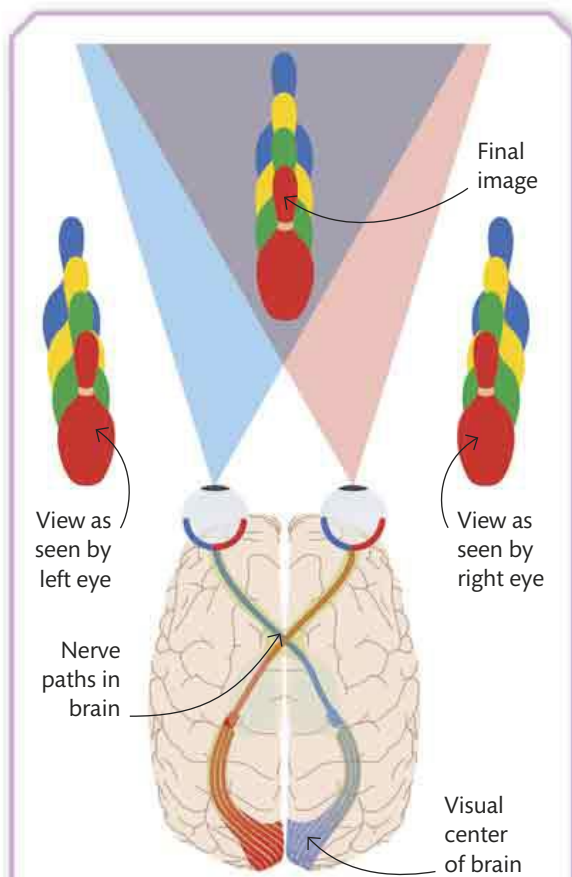
A scanning electron micrograph of the retina, showing a dense array of photoreceptors. The image is colorized, with rods appearing as blue, hair-like structures and cones as green, cylindrical structures. The background is a mottled brown and blue. A circular graphic with concentric lines is overlaid in the upper right corner, containing text.

“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 has eyes on the side of its head, both of a human's eyes face forward 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, color, and blur, gives us a tremendous ability to judge depth and distance, and see in glorious three dimensions (3D)—height, width, and depth.

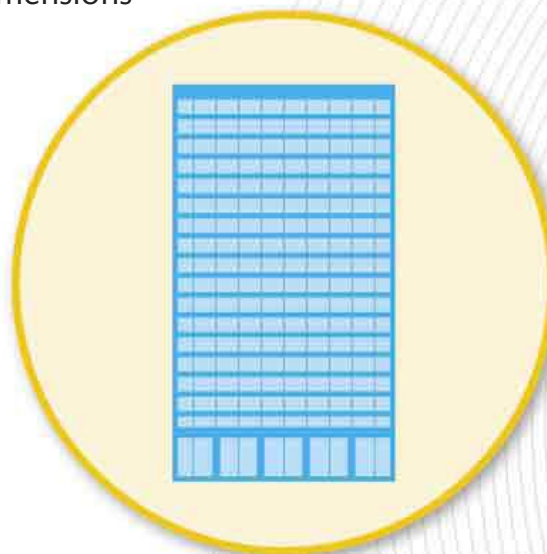


BINOCULAR VISION

Each eye sees a scene from its own angle. The vision center 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 closer it is. This is known as binocular or two-eye vision.

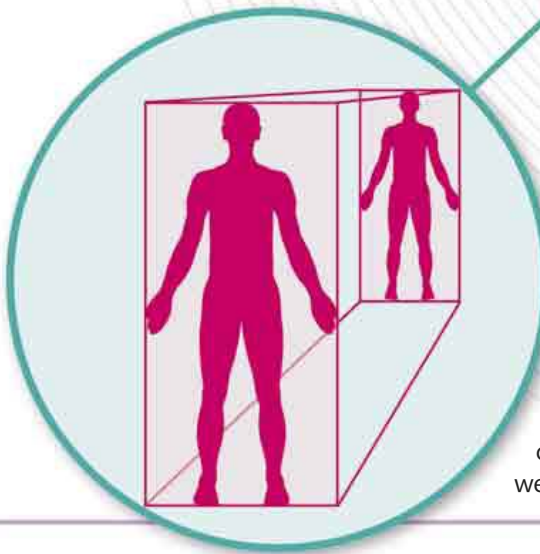
WORKING OUT A SCENE

This city street scene has all the components to help our eyes and brain create a complete image. Things like subtle changes in color, 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, trucks, and various animals. Checking their size in a scene such as a busy street allows us to guess how far away they are.



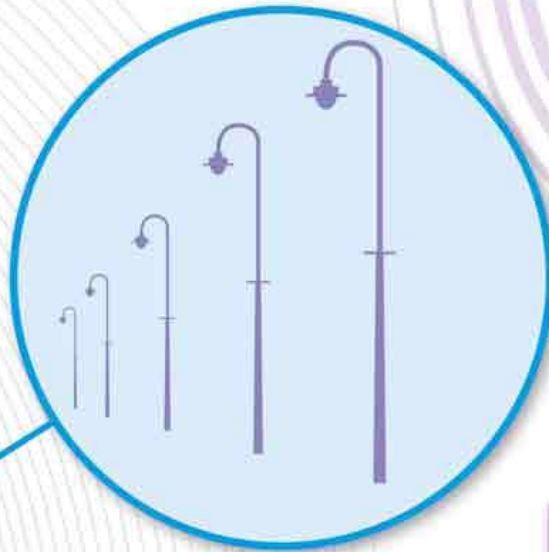
RELATIVE SIZE

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 closer.



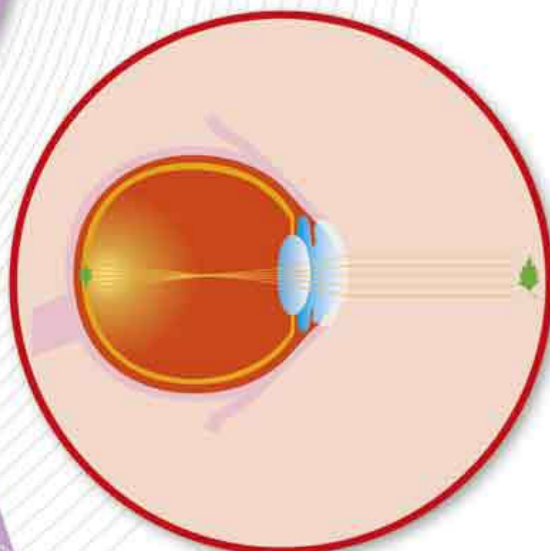
COLOR, FADE, AND SHADOW

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



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.



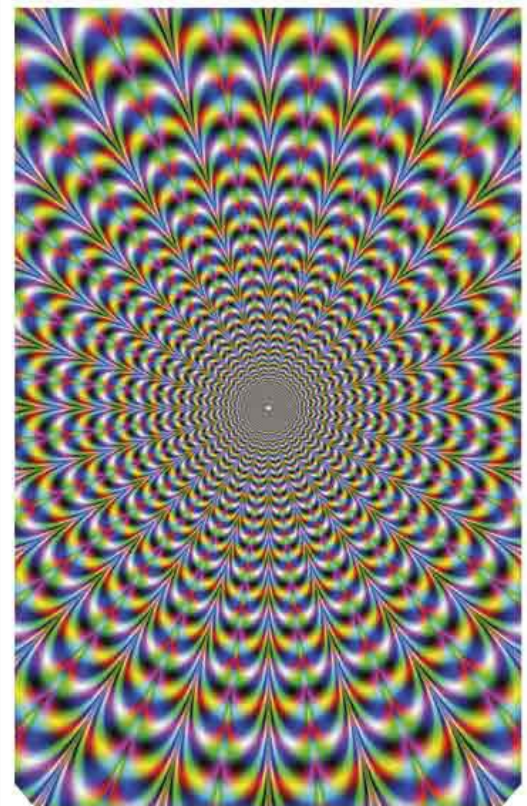
EYE FOCUS AND ANGLE

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 inward to look at nearer things.

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

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.



CROWDED AREAS MAKE OBJECTS LOOK NEARER



TOTALLY SENSATIONAL

“The human eye can see a bright flash of only 4 ms ($\frac{1}{250}$ of a second)”

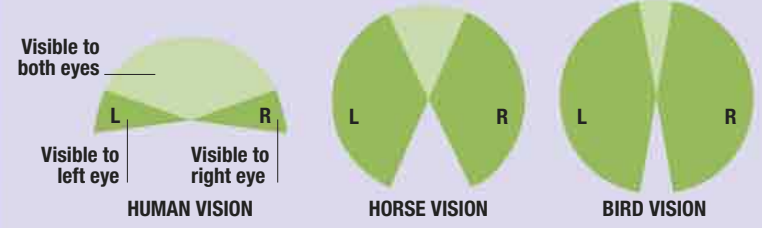
COMPLETE CONTROL

Total focus

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.

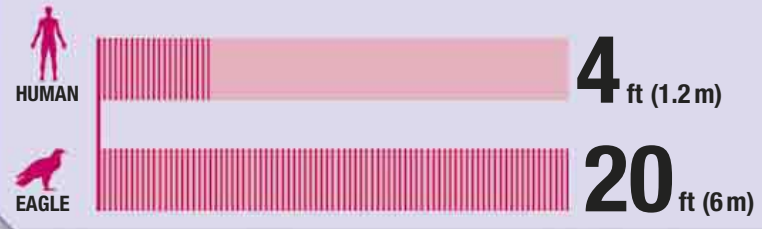
STATS AND FACTS

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 150 mph (240 km/h).

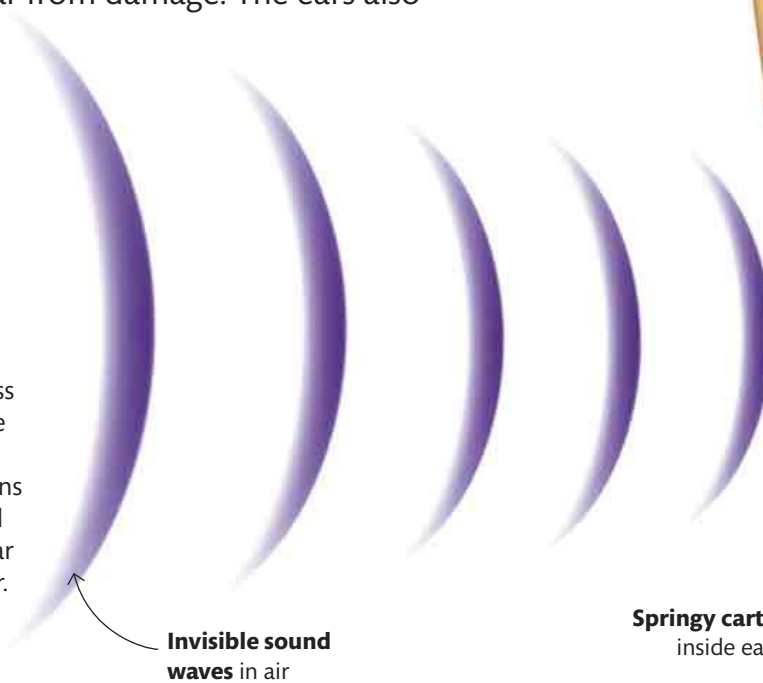
WIRED FOR SOUND

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 built-in 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 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 center.



Invisible sound waves in air

Pinna, skin covering of the ear flap

Springy cartilage inside ear flap

STATS AND FACTS

HEARING RANGE CHANGE



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

1 1/4 in (31.5 mm)

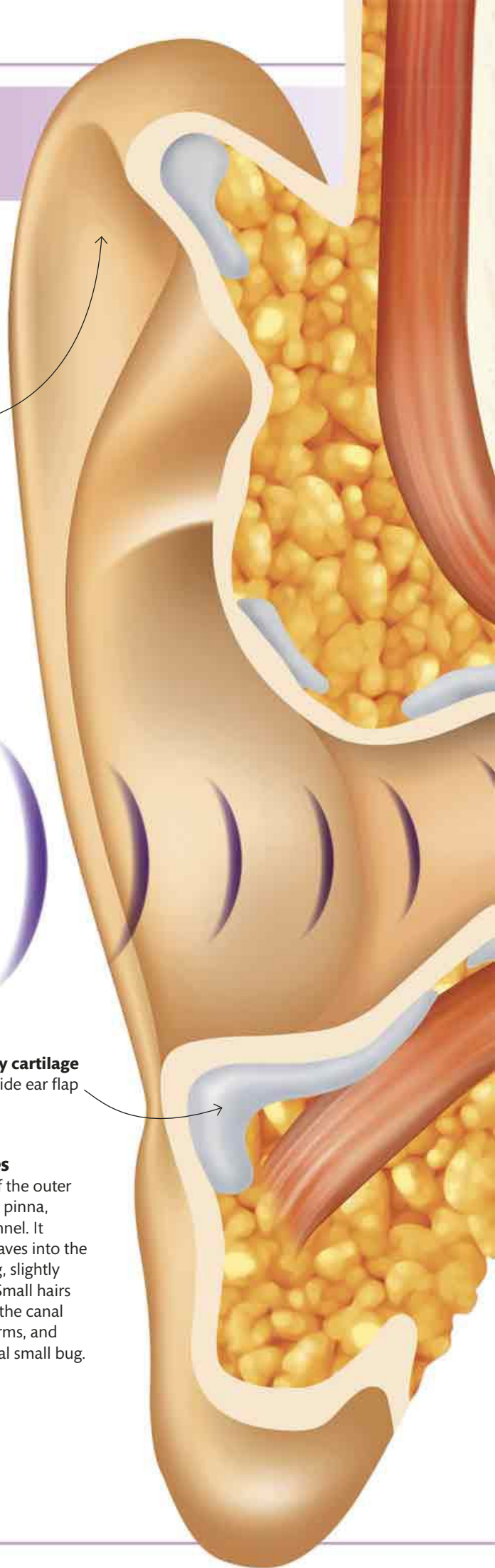
Inside each cochlea, there are around

15,000

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

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 1 in- (2.5 cm-) long, slightly curved ear canal. Small hairs and wax made by the canal lining trap dirt, germs, and even the occasional small bug.



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

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

Semicircular canals for balance (see pp. 96–97)

Cochlear nerve to the brain

Hammer bone

Eardrum,
thin membrane

Anvil bone

Stirrup bone

Ear canal
carries sound waves
to the eardrum

Fatty tissue

**THE COCHLEAR NERVE
HAS 30,000
NERVE FIBERS**

Vibrations travel
through the cochlea

Cochlear fluid
vibrates hair cells

Organ of Corti,
spiral canal inside
the cochlea

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, microhairs poke from the dished surface of a single outer hair cell. This is surrounded by ridges, and beyond are the similar downcurved surfaces of neighboring cells.

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

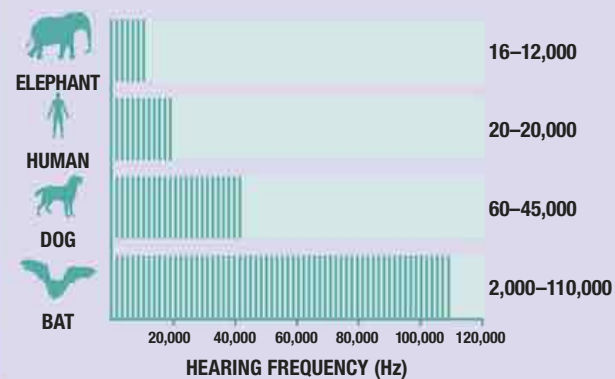
HAIRS THAT HEAR

Inside the cochlea

Deep in the ear, the cochlea—itself about the size of a pea—contains around 15,000 specialized microscopic hair cells. Each has a batch of even tinier microhairs called stereocilia on its surface. The hairs jut into a sticky fluid called endolymph and touch a jellylike 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, 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

It takes 0.03 seconds to correct sudden imbalance



Eyes judge horizontals and verticals, such as walls and floors

Cerebellum in the lower rear brain compares different inputs

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 center.

Sensors in the knee joint detect how much the knee is bent

Muscle sensors detect contraction



“Even standing still uses more than 300 muscles”

Stretch sensors detect when the skin tightens

Semicircular canals at right angles to each other so they detect movement across any angle

Nerve from ear to brain

IN THE EAR

Five ear parts give balance information. Head movement makes liquid inside the three ear canals swish, bending the microhairs 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.

Utricle

Swishing liquid

Microhairs of hair cells in jellylike blob, or cupula

Touch receptors in skin respond to pressure on sole to detect leaning

STATS AND FACTS

TIGHTROPE CROSSING

Fastest 328 ft (100 m) tightrope walk

45 seconds

Longest tightrope crossing by bicycle

235 ft
(71.6 m)

Most skips on a tightrope

1,323

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

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



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.

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.

A high-angle, low-light photograph of a surfer riding a barrel wave. The surfer is in a crouched, balanced position on a yellow surfboard, navigating the tunnel of the wave. The water is a deep, vibrant blue, and the wave's face is illuminated from above, creating a dramatic contrast. The overall mood is one of intense focus and physical challenge.

**“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 flavors 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 flavors 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.

Some papillae have tiny fingers that act like a rasp and help clean the tongue

Saliva carries dissolved substances into the taste pore

MIGHTY MUSCULAR

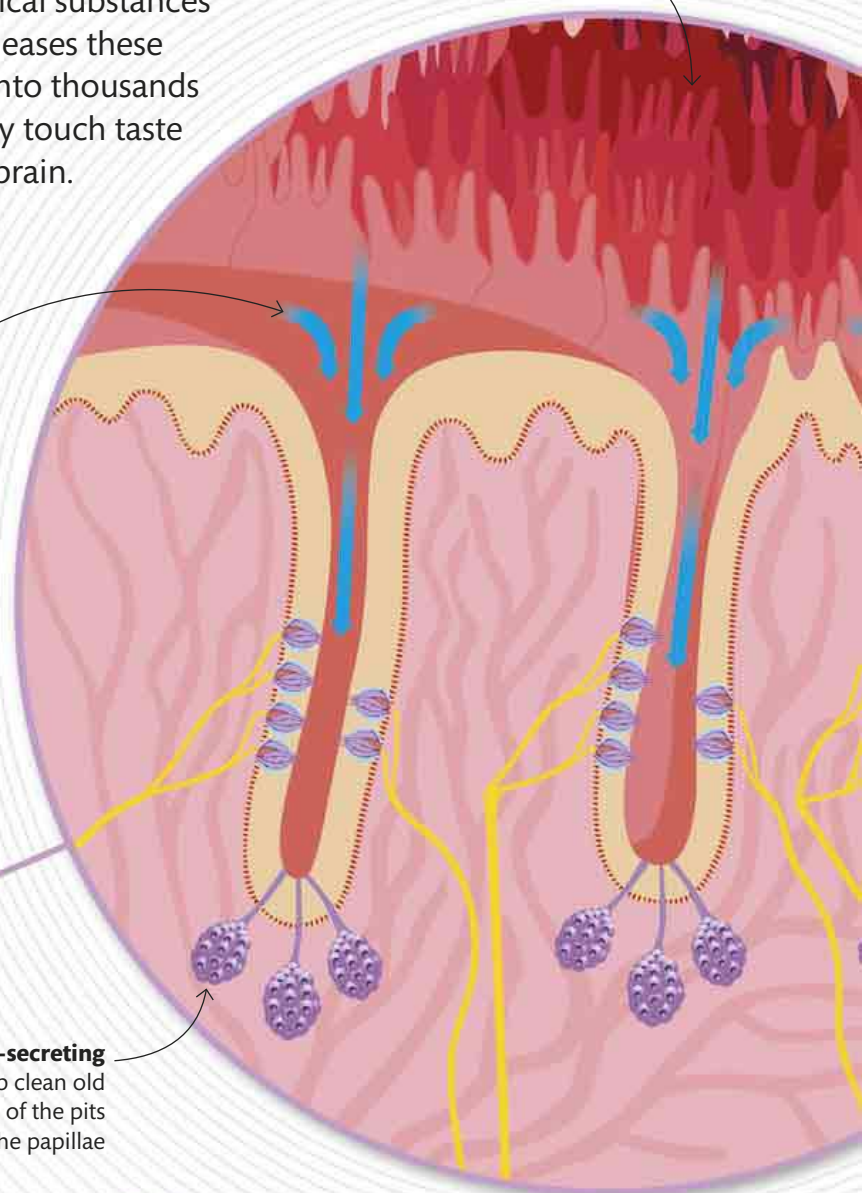
The tongue is almost all muscle, making it powerful and flexible. More than four-fifths of the taste buds lie on its upper surface, sides, and tip. There are also taste buds scattered on the inner lips, insides of the cheeks, roof of the mouth (palate), throat, and epiglottis.

Mucus-secreting glands help clean old tastes out of the pits between the papillae

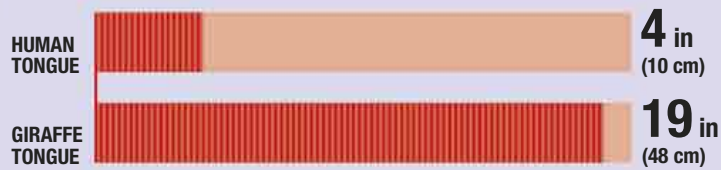
A TONGUE PRINT IS AS UNIQUE AS A FINGERPRINT

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 less 1mm across.



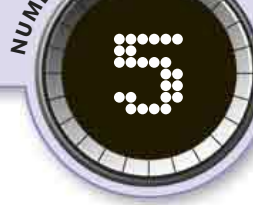
STATS AND FACTS



NUMBER OF WORKING TASTE BUDS

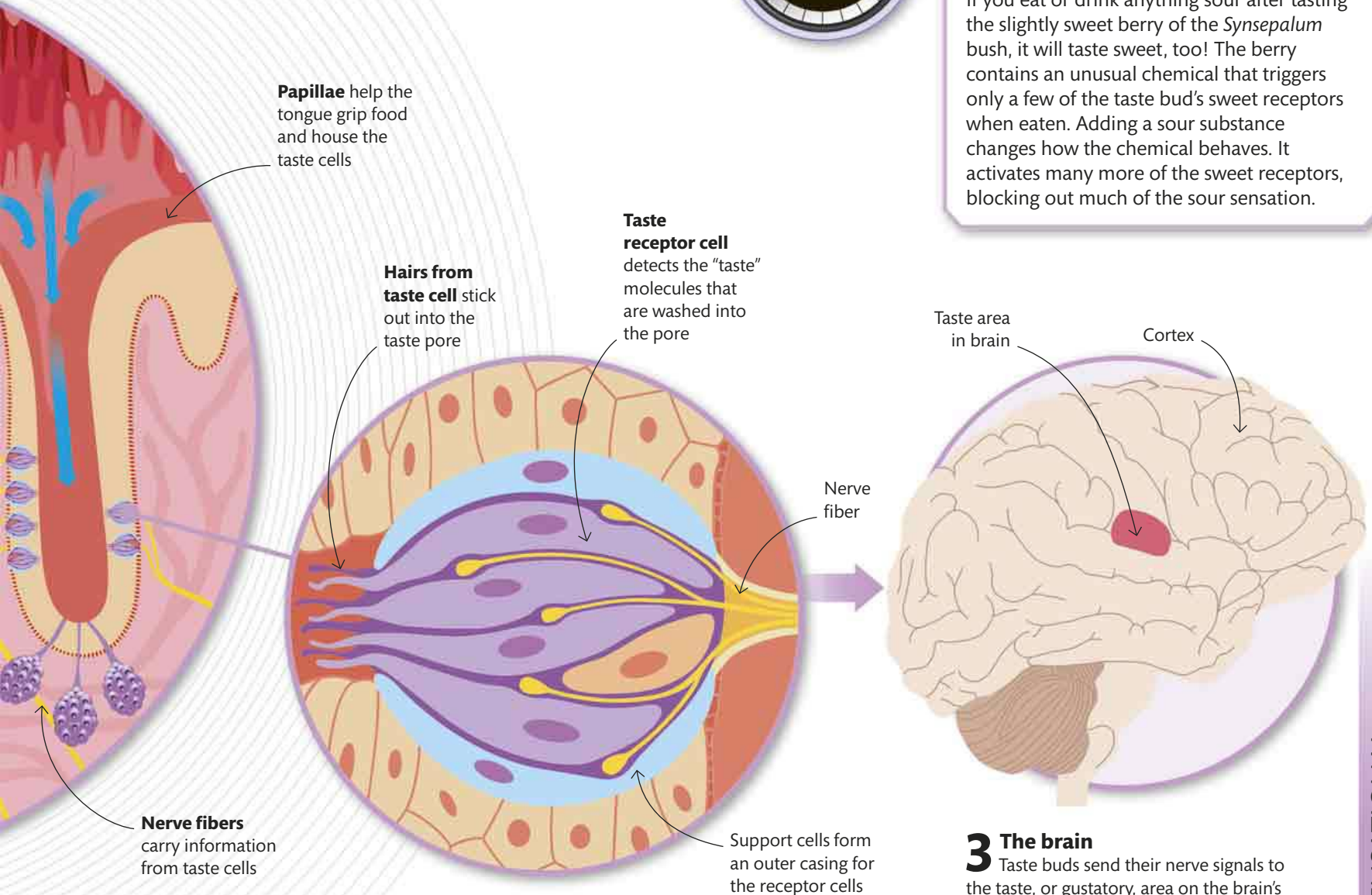


NUMBER OF BASIC TASTES



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 tiny orange with about 25 taste receptor cells plus support cells. The tips of the receptor cells have narrow, hairlike 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 fibers.

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 flavors. 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 savory (umami). Eighty percent of the flavor of food is actually detected by our sense of smell.

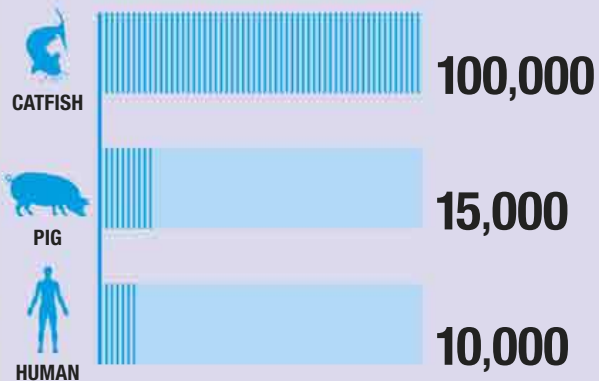
ON THE TONGUE

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

NUMBER OF TASTE BUDS



Food's-eye view

Fingerlike papillae (colored 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.

A scanning electron micrograph (SEM) of a taste bud. The image shows a dense, textured surface of numerous small, finger-like projections called microvilli. In the center, a larger, rounded structure is visible, which is the taste cell. The overall appearance is highly detailed and complex, with a color palette dominated by shades of purple and blue.

**“Taste bud
cells live for only
10-11 days
before they are
replaced”**

ON THE SCENT

How we smell things

Life without scents, perfumes, odors, and aromas would be very dull. Our suppersense of smell can tell apart millions of different odors. It helps us 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”

Odor molecules drift in air currents

FROM AIR TO BRAIN

As with taste, our sense of smell is based on chemistry. Receptor cells in the nose detect odor 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 odors from hundreds of yards away.

1 Odors in air

Each of the chemicals in an odor molecule has a unique structure that binds to a particular type of receptor in the nose. Most odor molecules are small and light, and float easily in air.

4 Bulb and brain

The receptors pass on millions of nerve messages to the olfactory bulb located just above them. The bulb sorts and coordinates these messages. It then sends them along the short, thick, nerve-like olfactory tract to the brain's smell-processing center.

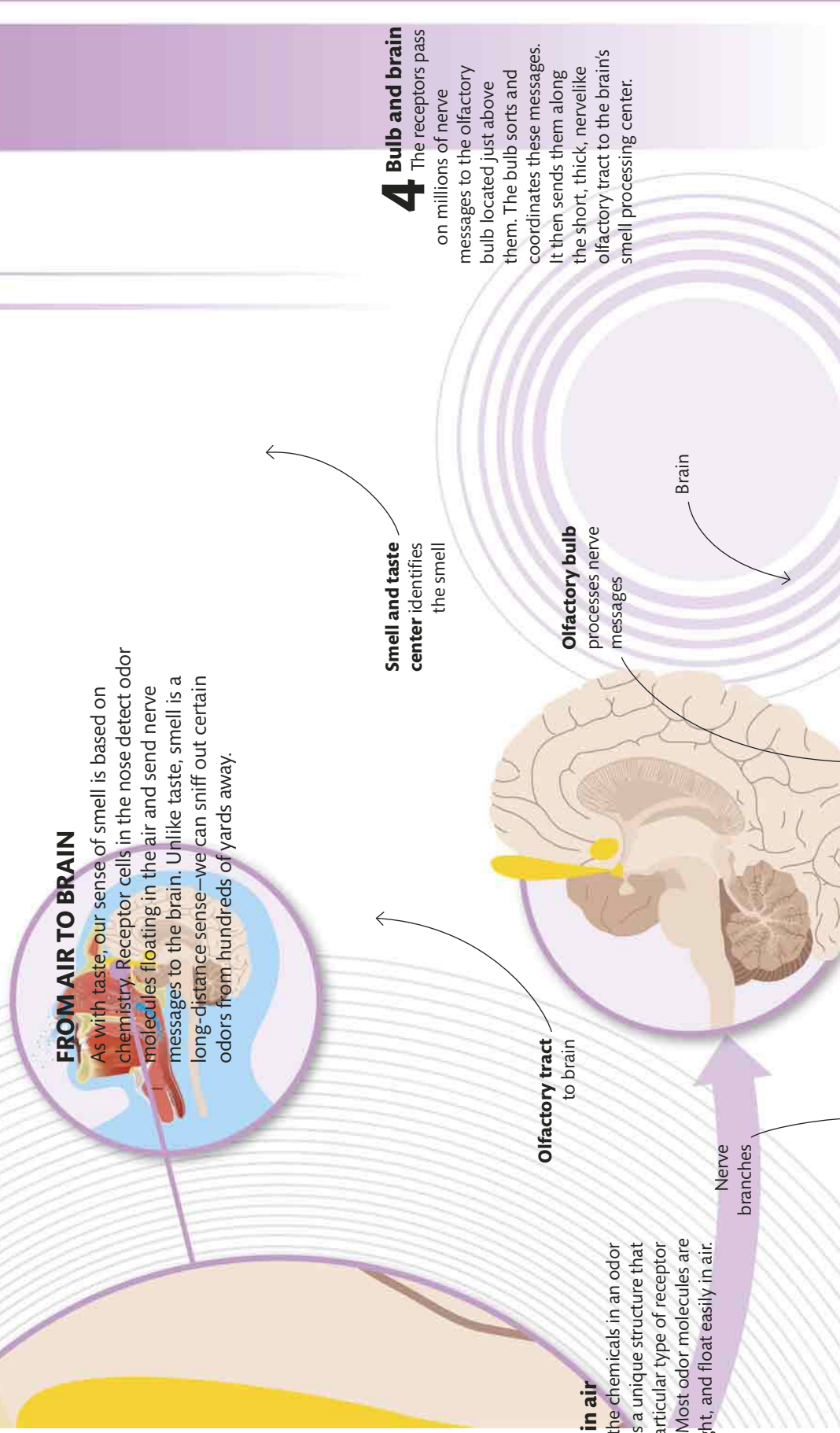
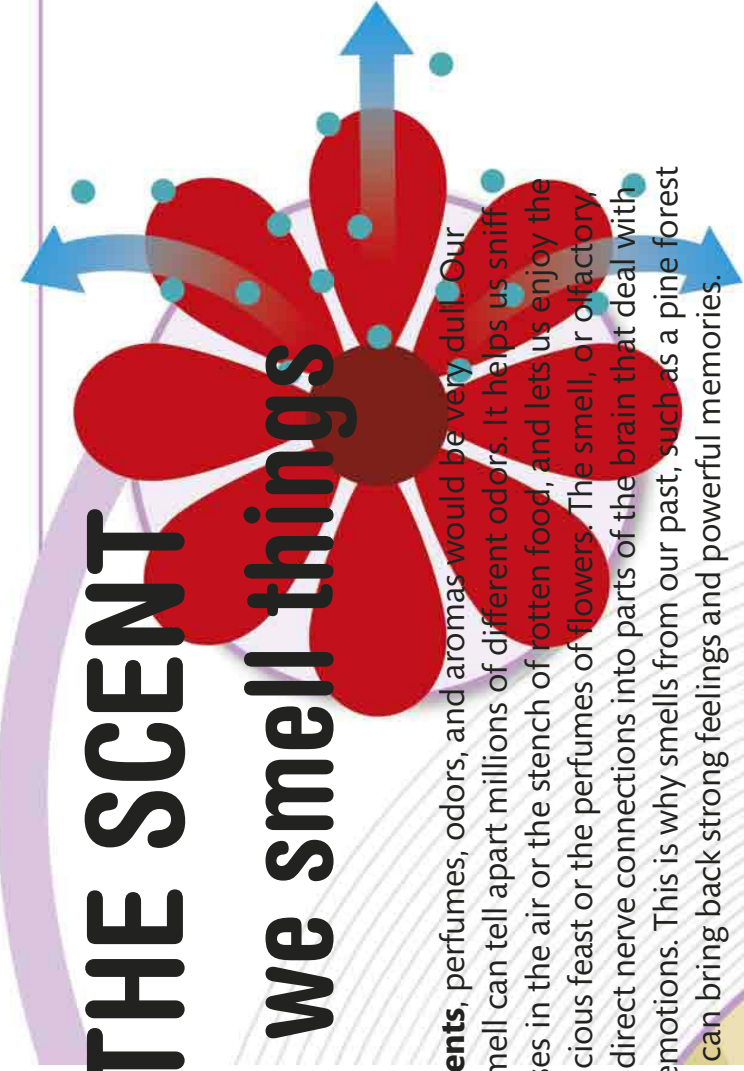
Smell and taste center identifies the smell

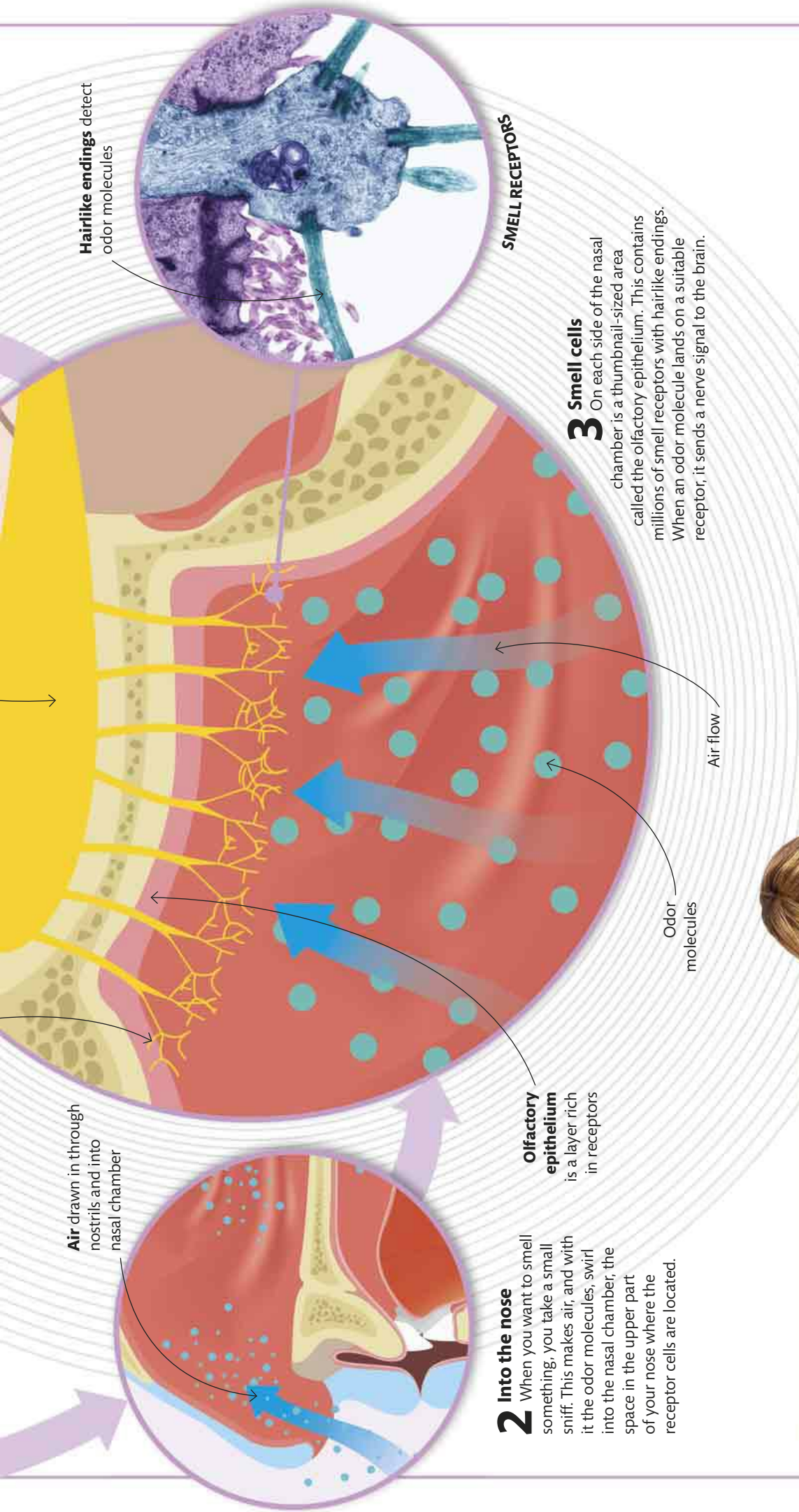
Olfactory bulb processes nerve messages

Brain

Olfactory tract to brain

Nerve branches





2 Into the nose

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

Olfactory epithelium is a layer rich in receptors

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 hairlike endings. When an odor molecule lands on a suitable receptor, it sends a nerve signal to the brain.



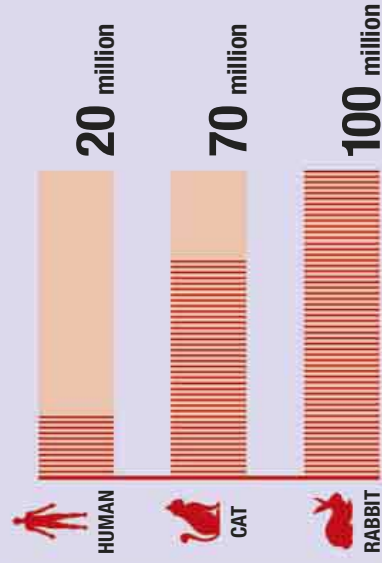
Nasal passage closed partially to prevent foul smell from entering

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 odor 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.

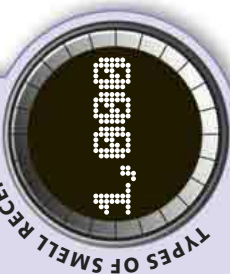
STATS AND FACTS

SMELL CELLS



DETECTION

1 trillion smells can be detected by the human nose



KEEPING IN TOUCH

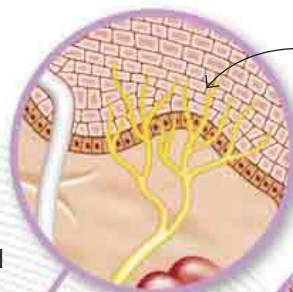
How we feel sensations

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 contacts 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.

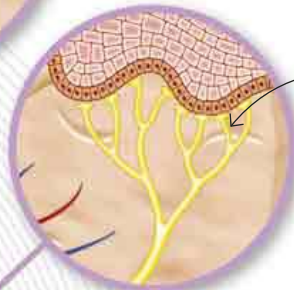
“If the body was as tall as the Eiffel Tower, the fingertips would be able to feel ridges less than 1mm high”

TYPES OF TOUCH RECEPTORS

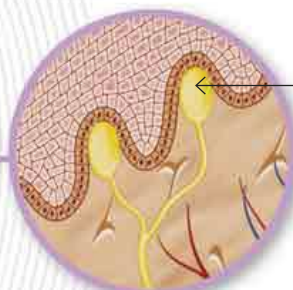
The skin has millions of touch receptors of various kinds. Some are near the surface; others are buried deeper. Certain types respond to several kinds of change, such as being pressed, heated, cooled, squeezed, stretched, or vibrated, while others respond to only a few types of change.



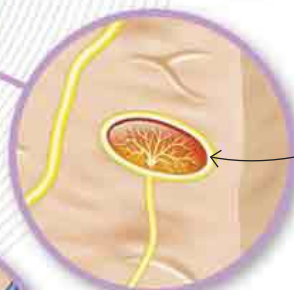
Free nerve endings are like tiny branching trees and are affected by most kinds of change in touch—they also register pain.



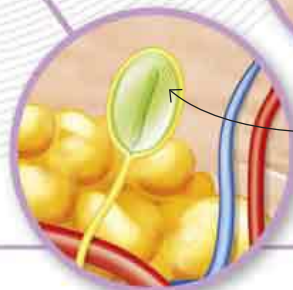
Merkel endings are located near the skin's surface and they are especially sensitive to medium levels of touch, pressure, and slower vibrations.



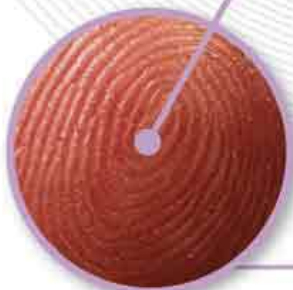
Meissner endings sit just below the epidermis and respond to very light, brief touches as well as faster vibrations.



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

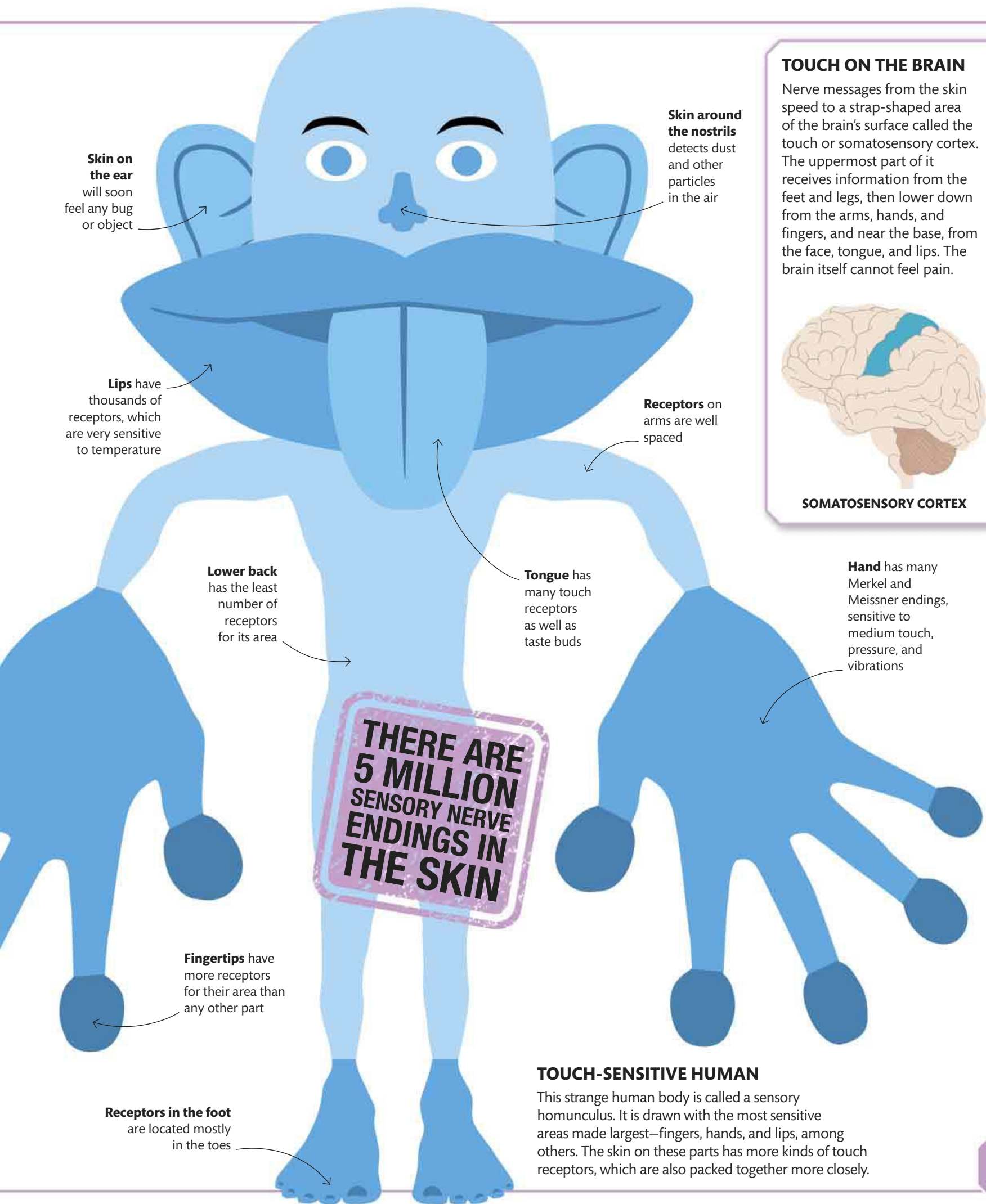


Pacinian endings are the deepest and largest type of touch receptor; they respond to prolonged pressure and all kinds of vibrations.



HUMAN SKIN





Skin on the ear will soon feel any bug or object

Skin around the nostrils detects dust and other particles in the air

Lips have thousands of receptors, which are very sensitive to temperature

Receptors on arms are well spaced

Lower back has the least number of receptors for its area

Tongue has many touch receptors as well as taste buds

Hand has many Merkel and Meissner endings, sensitive to medium touch, pressure, and vibrations

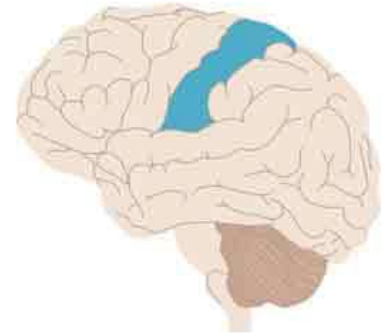
THERE ARE 5 MILLION SENSORY NERVE ENDINGS IN THE SKIN

Fingertips have more receptors for their area than any other part

Receptors in the foot are located mostly in the toes

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 $\frac{1}{5000}$ th 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 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.

Touch cortex establishes location of pain

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).

Frontal cortex becomes aware of pain

Parts of the limbic system are linked to emotions of pain

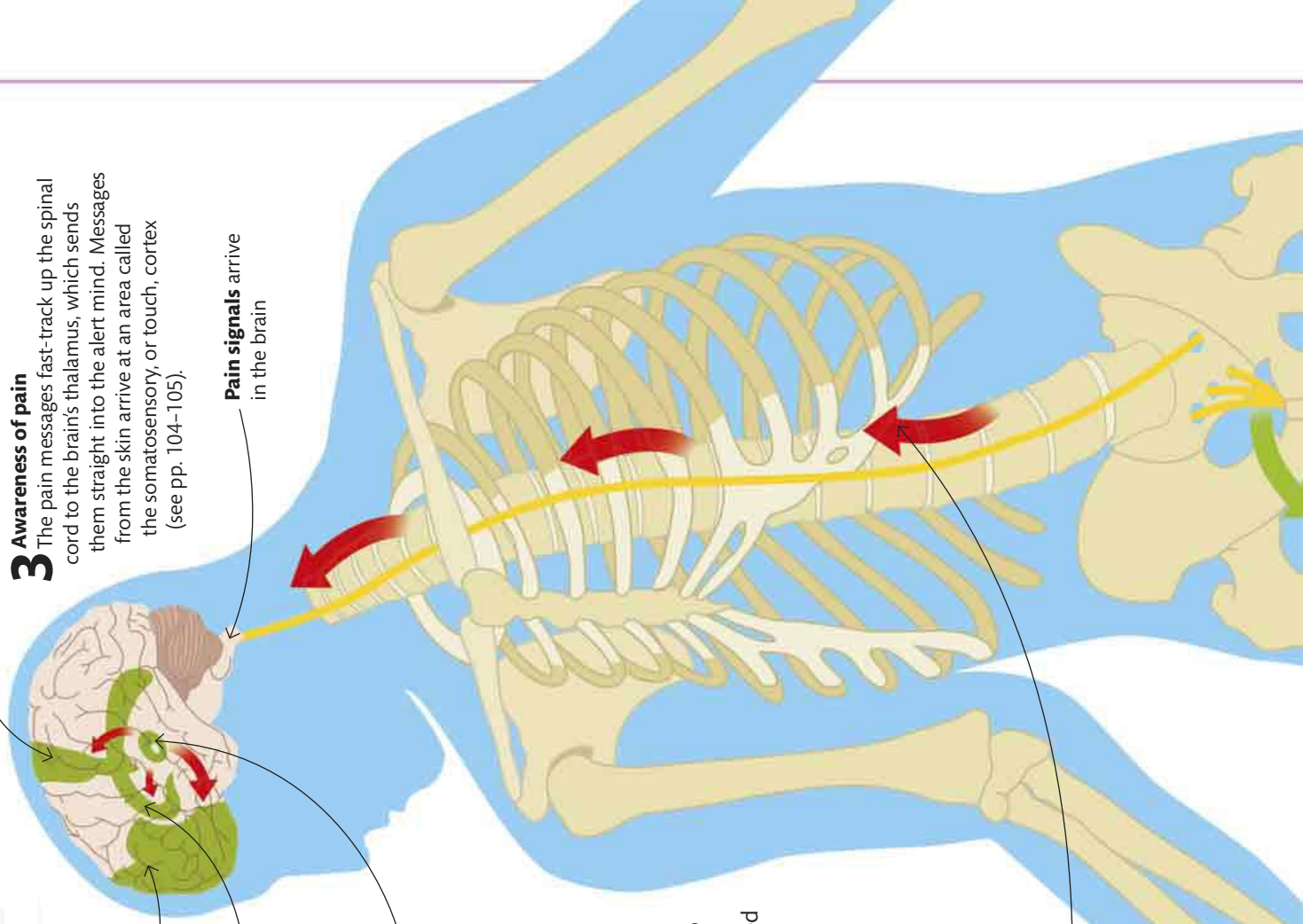
Thalamus relays signals to cortex

Pain signals arrive in the brain

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 fibers at up to 160 ft (50 m) per second. In the brain they are routed straight to the conscious awareness, so the mind can take urgent action.

Pain signals move up the spinal cord toward the brain





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 chili peppers 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 $\frac{1}{15}$ OF A SECOND





POWER SYSTEMS

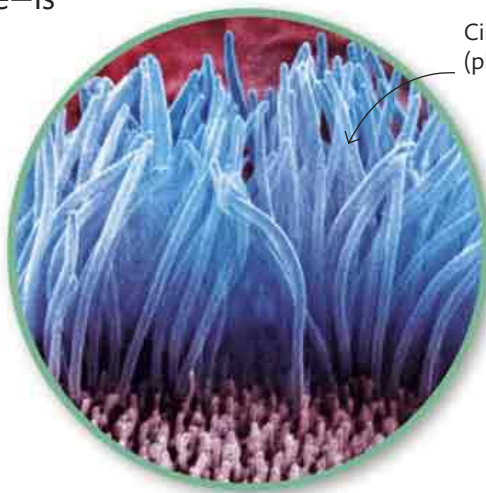
Regular, reliable, and dependable, every second the lungs breathe, the heart beats, and the pulse throbs as the blood flows. The rest of the body relies on these supersystems never to pause or lose their power.

BREATHING MACHINE

Lungs and airways

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.

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



CLEANING YOUR AIR

The windpipe and main airway linings have millions of microhairs 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.

2,500 ALVEOLI WOULD FIT ON A FINGERNAIL

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

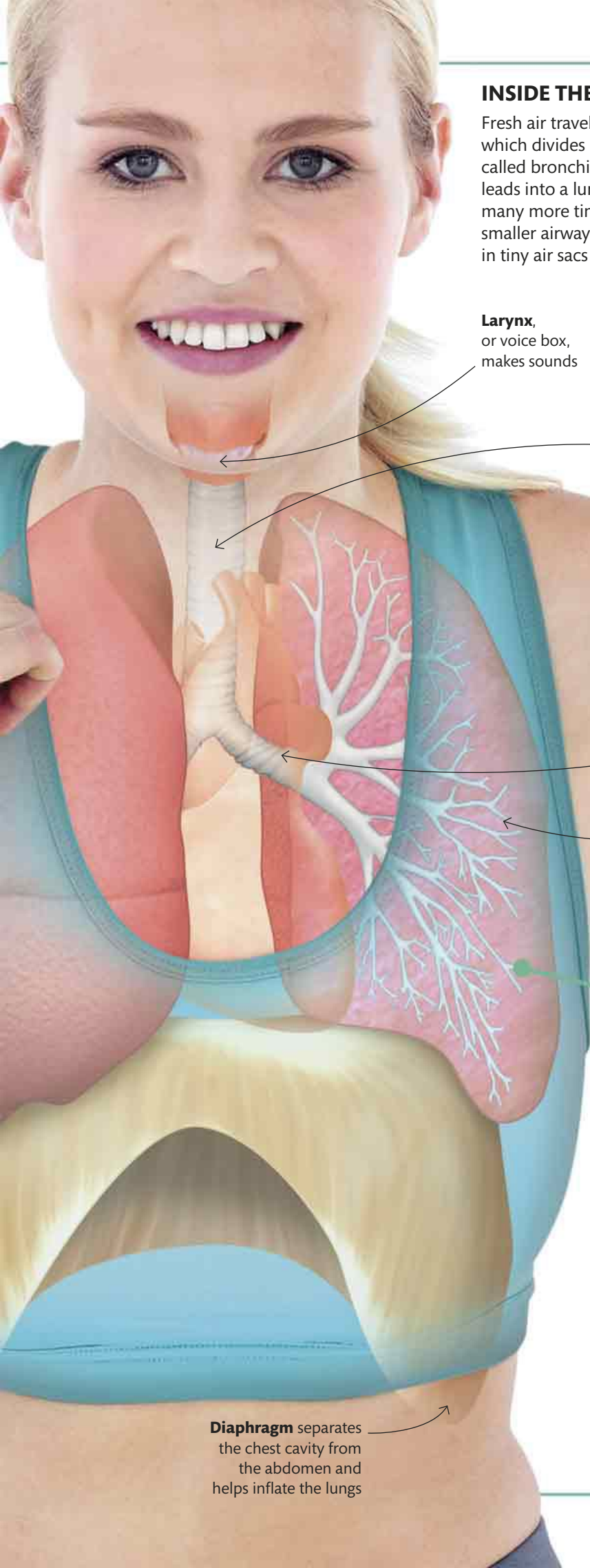
STATS AND FACTS

TOTAL VOLUME OF BOTH LUNGS



BREATHING CAPACITY





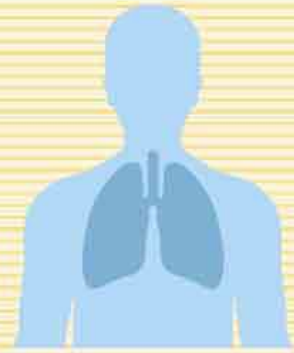
INSIDE THE CHEST

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.

Larynx, or voice box, makes sounds

Trachea, or windpipe, carries air to and from the lungs

AT A GLANCE



■ **SIZE** Height of each lung 12 in (30 cm), weight about 1.3 lb (0.6 kg)

■ **LOCATION** Fill 90 percent 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

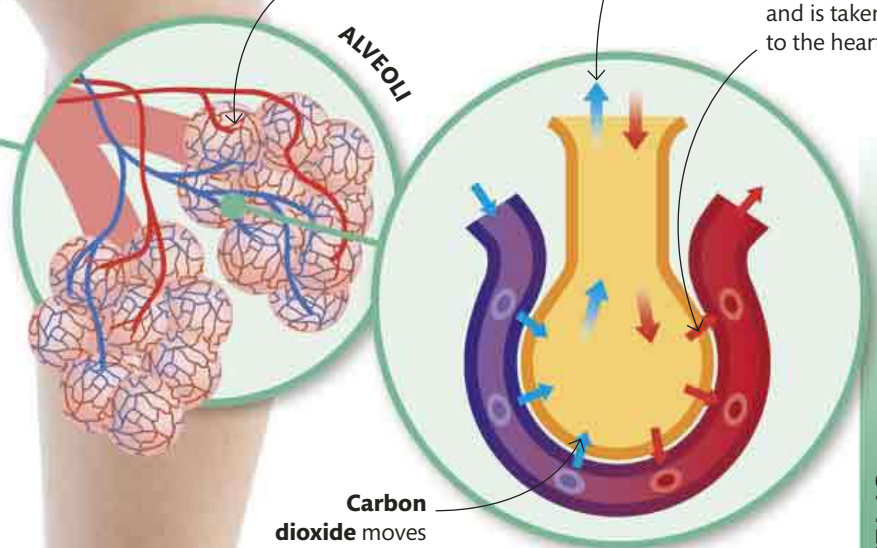
Bronchus (plural bronchi) branches from the windpipe

Bronchioles are the smaller branches from the bronchus. There are around 30,000 bronchioles in each lung

Network of capillaries encasing air sacs

Carbon dioxide is breathed out of the body

Oxygen is drawn into the capillary and is taken to the heart



Carbon dioxide moves from the blood into the alveolus

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.

Diaphragm separates the chest cavity from the abdomen and helps inflate the lungs

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 quarts (6 liters) 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

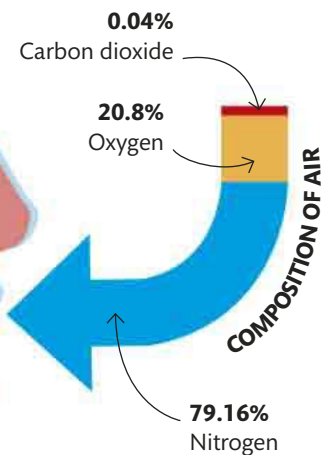
50–60

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.



Ribs form a movable protective cage around the lungs

Lungs expand as the rib muscles tighten and the diaphragm pulls down, sucking in air

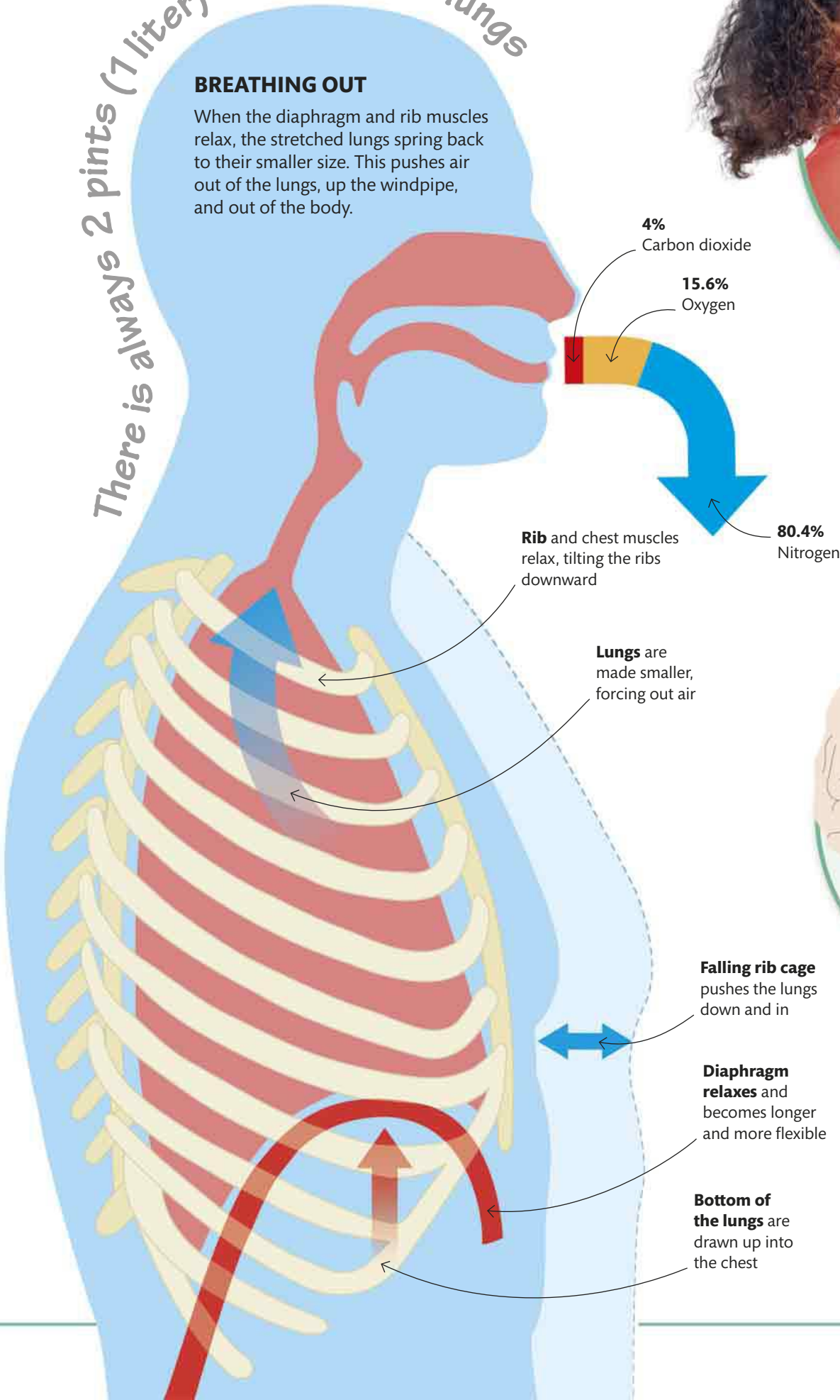
Diaphragm is a dome-shaped sheet of muscle under the lungs

Diaphragm tightens, pulling the bottom of the lungs down

There is always 2 pints (1 liter) 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.



4% Carbon dioxide

15.6% Oxygen

80.4% Nitrogen

Rib and chest muscles relax, tilting the ribs downward

Lungs are made smaller, forcing out air

Falling rib cage pushes the lungs down and in

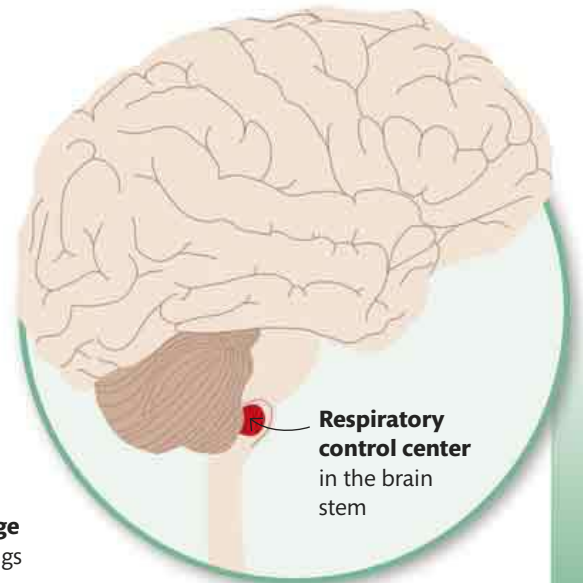
Diaphragm relaxes and becomes longer and more flexible

Bottom of the lungs are drawn up into the chest



UNDER PRESSURE

The breathing system can produce enough air pressure to push water more than 6 ft (2 m) 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.



Respiratory control center in the brain stem

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.

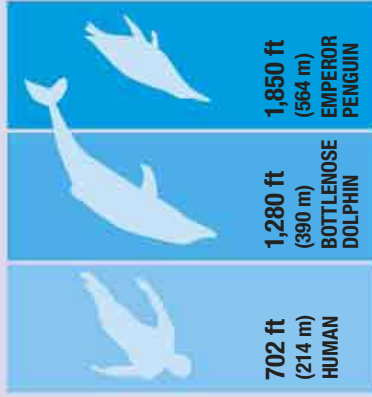
HUMAN SUB

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 center 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



RECORD SWIM




HOLD YOUR BREATH



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

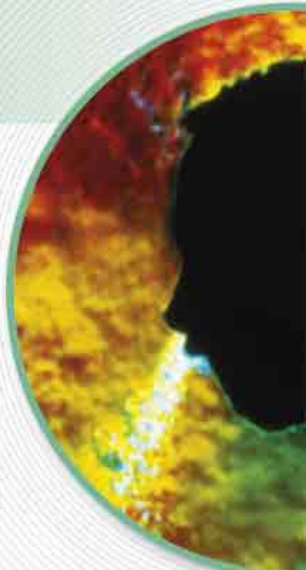
SCREAM AND SHOUT

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

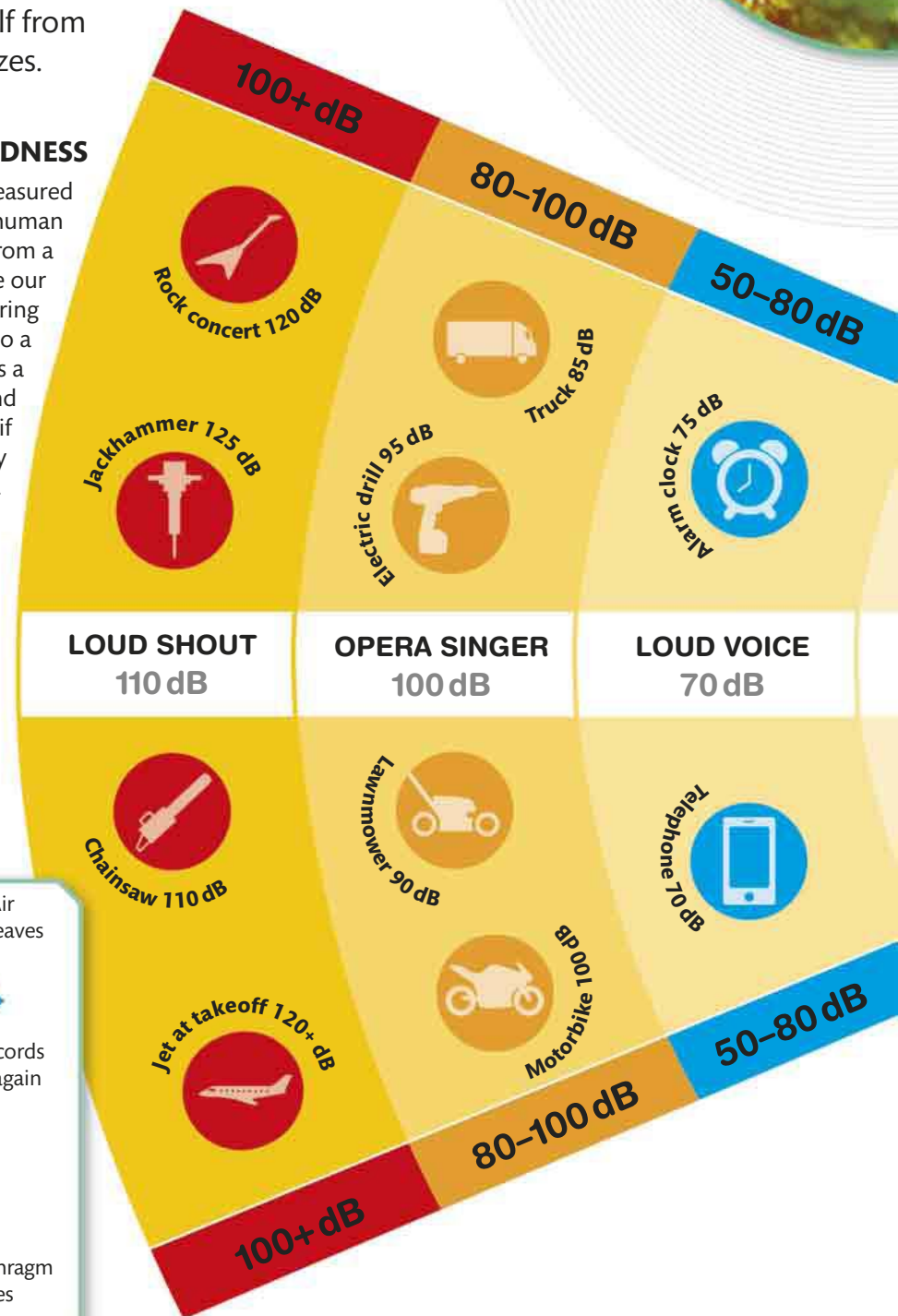
A sneeze is a sudden blast of air out of the nose that blows away drops of mucus and dust at speeds of up to 100 mph (160 km/h). Coughing is used to clear the lower airways and windpipe, rattling the vocal cords as it comes out of the mouth. The air travels up to 45 mph (72 km/h) and sprays tiny drops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



COMPARING LOUDNESS

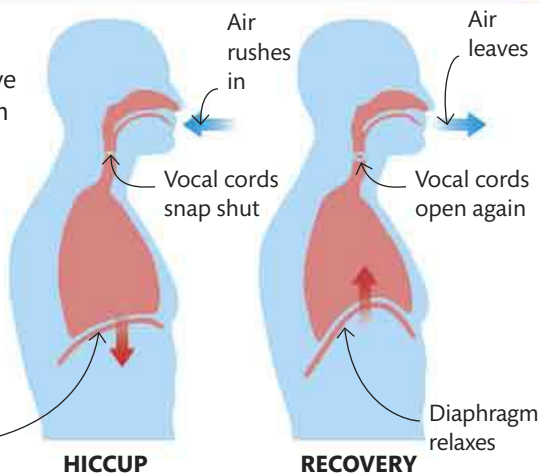
Loudness, or volume, is measured in decibels (dB). The human voice can range from a whisper—just above our lower range of hearing of 0–5 dB—to a shout as loud as a chainsaw: a sound that would hurt if it was right by your ear.

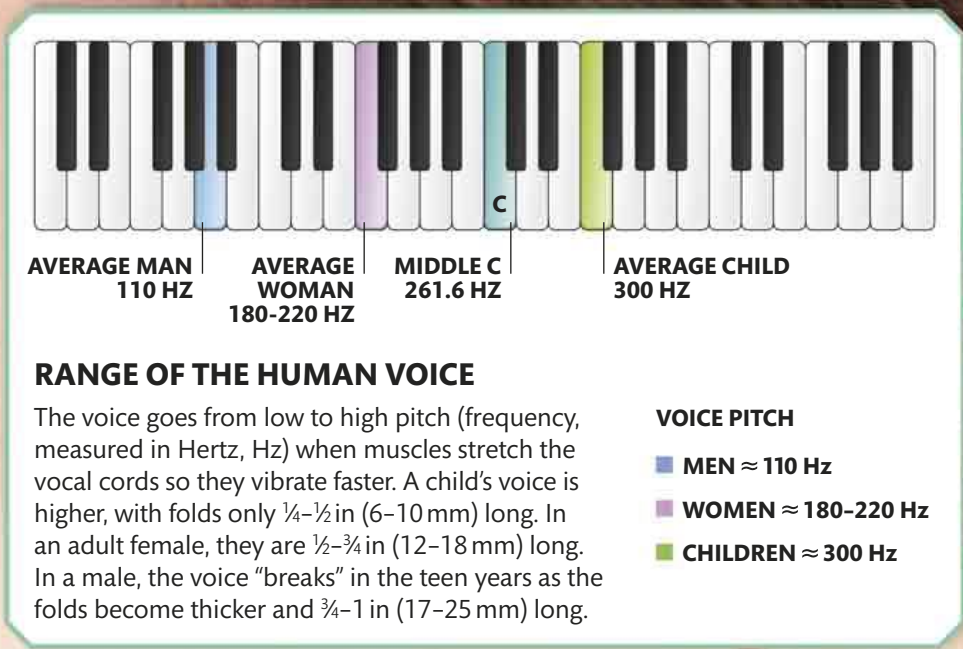
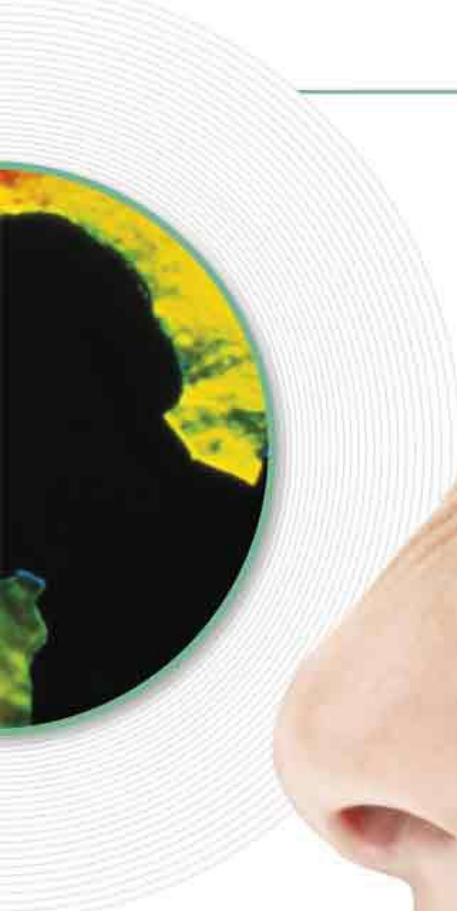
“Some snorers are louder than a low-flying jet, reaching 110 decibels”



HICCUPS

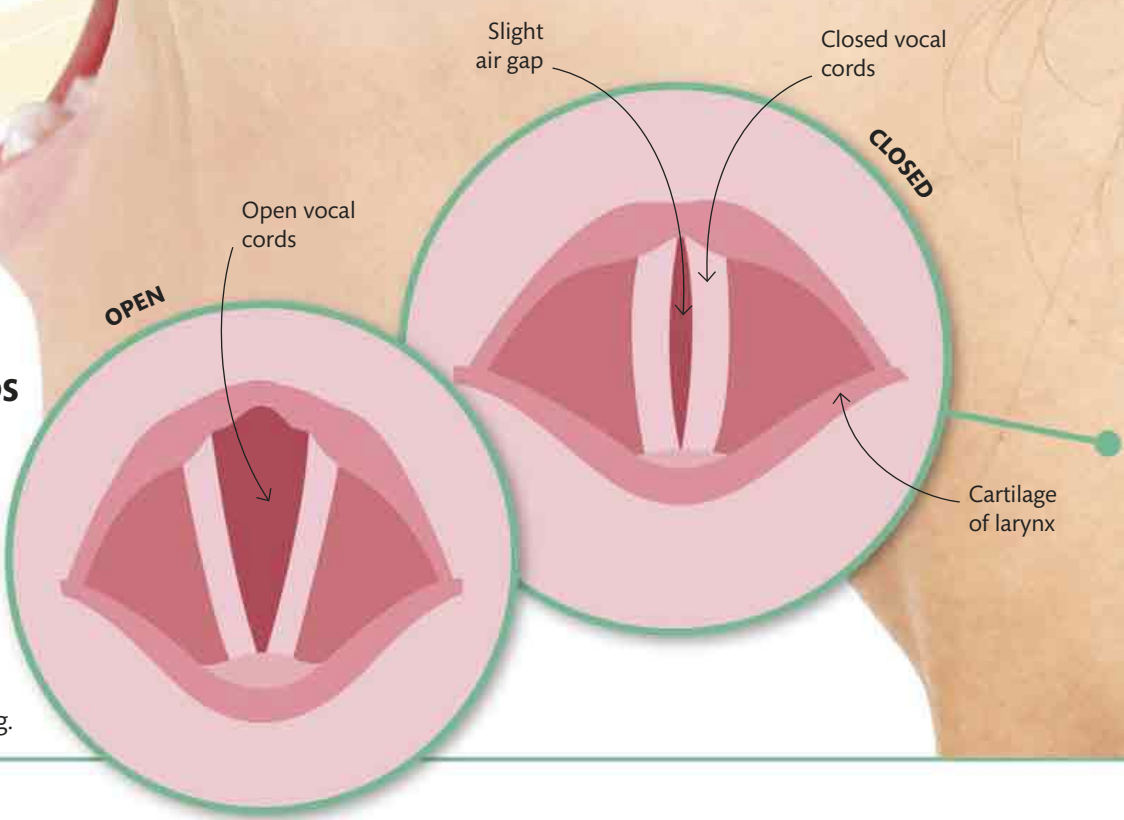
Hiccups happen when nerve signals make the diaphragm muscle contract sharply. There are many causes—from eating or drinking too much or too fast, to a sudden fright or cough. There are many remedies, too—from sipping a drink to another sudden fright!





VOCAL CORDS

When you speak, you activate your vocal cords, which are two strong, shelflike 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

Every part of the body needs oxygen and nutrients that make energy, to stay alive. 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 around and around. 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 vessels. 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.

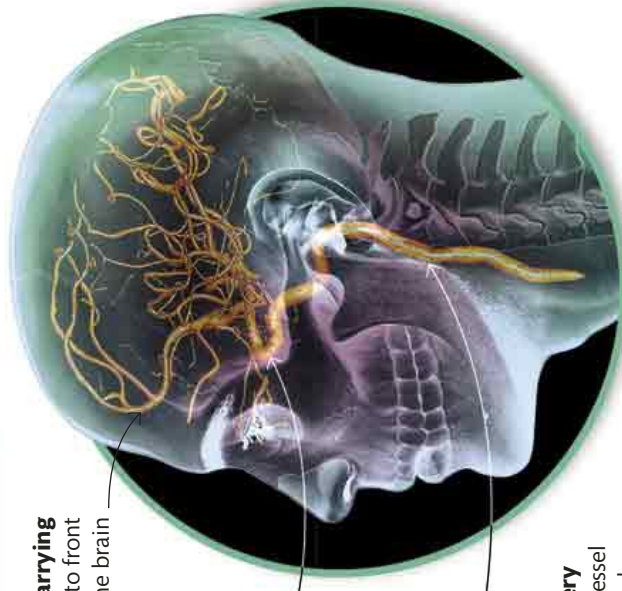
Pulmonary vein
returns high-oxygen
blood to the heart

Pulmonary artery
carries low-oxygen
blood to the lungs

Heart

Renal artery delivers
high-waste blood to the kidney

Renal vein takes cleaned
blood back to the vena cava



Artery carrying blood to front part of the brain

Artery carrying blood to eyes, nose, and forehead

Artery entering the skull

Carotid artery is the main vessel carrying blood to the brain

BLOOD TO THE BRAIN

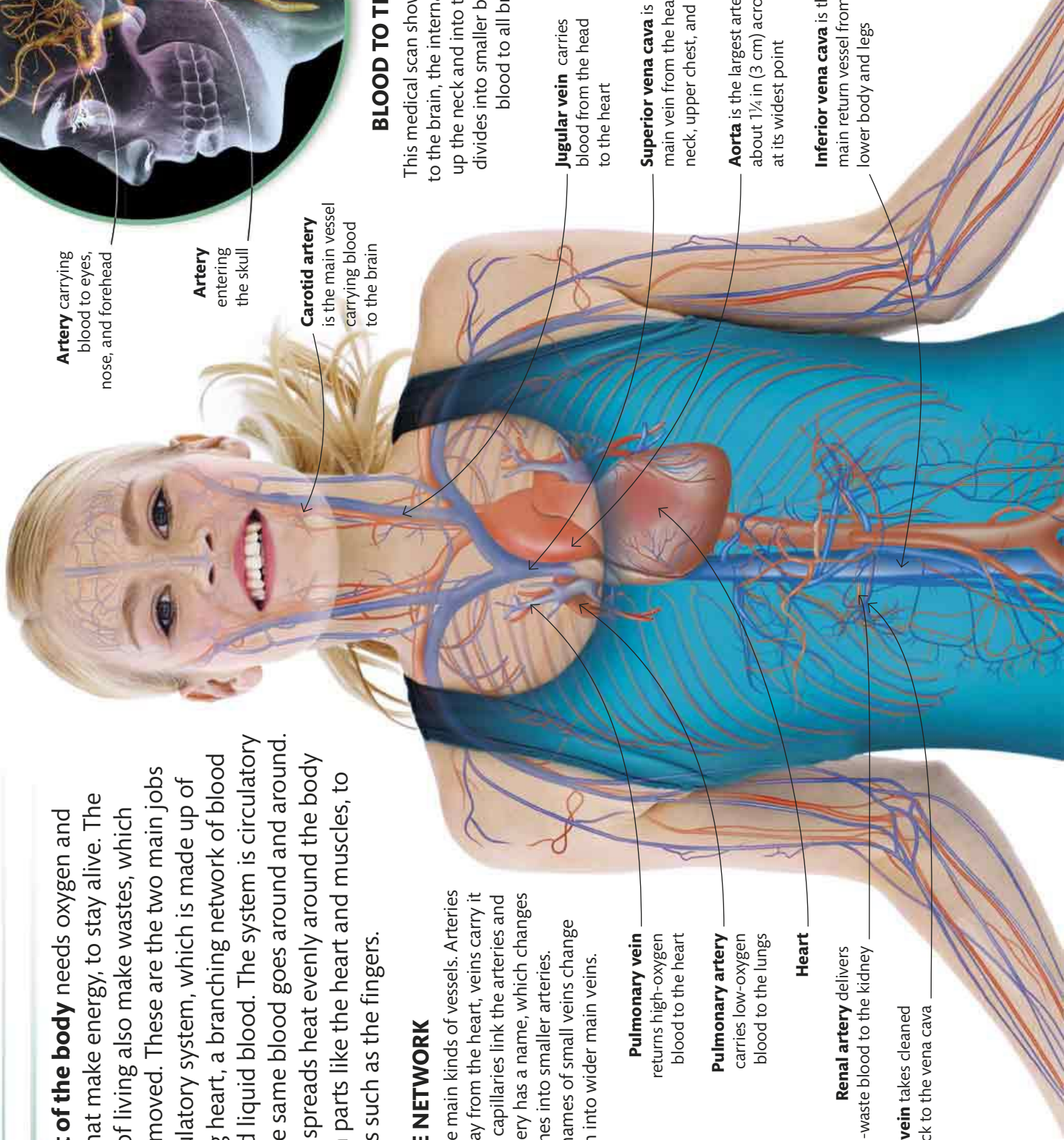
This medical scan shows the main artery to the brain, the internal carotid. It passes up the neck and into the skull, and then divides into smaller branches that take blood to all brain parts.

Jugular vein carries blood from the head to the heart

Superior vena cava is the main vein from the head, neck, upper chest, and arms

Aorta is the largest artery, about 1¼ in (3 cm) across, at its widest point

Inferior vena cava is the main return vessel from the lower body and legs



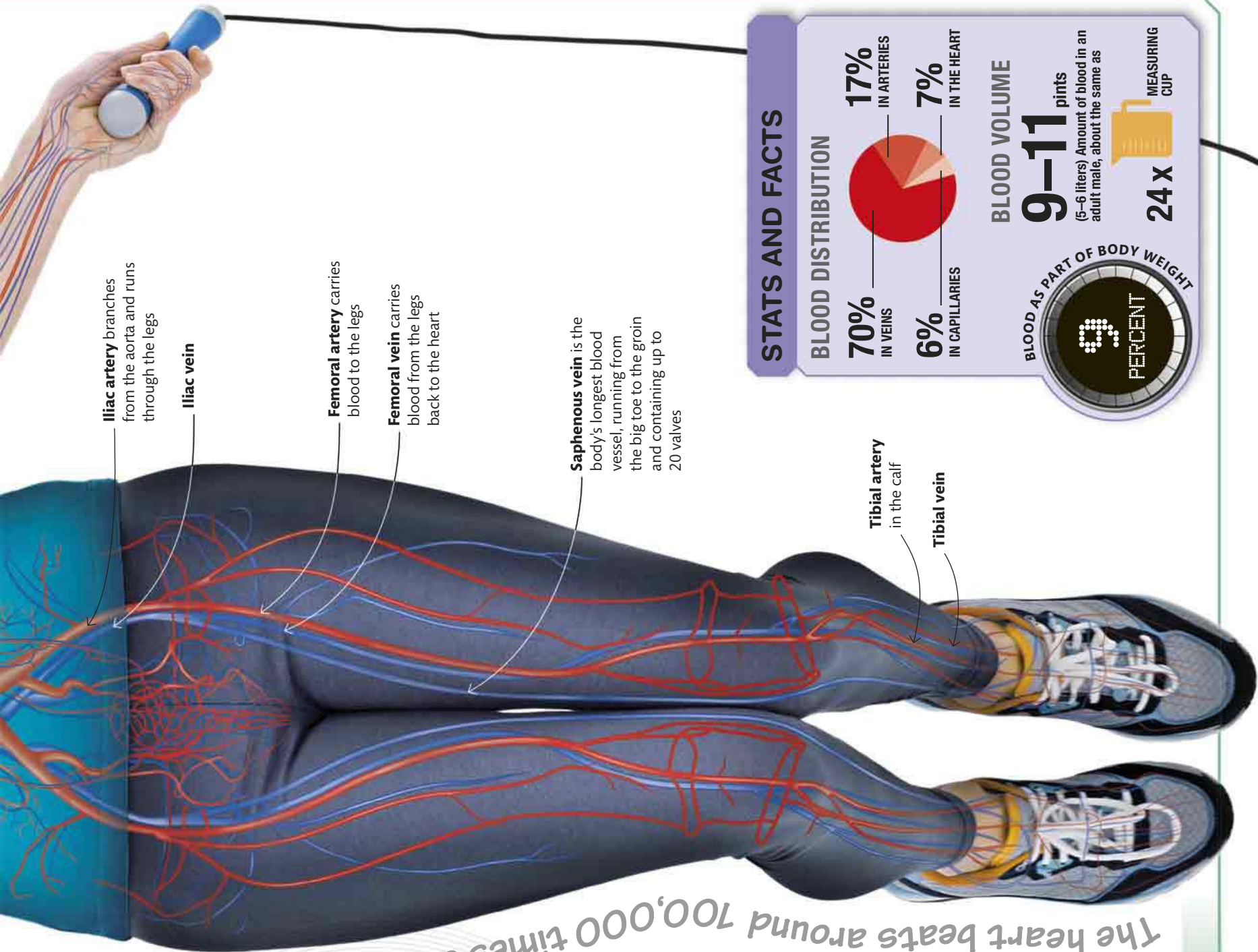


The heart beats around 100,000 times each day

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”



Iliac artery branches from the aorta and runs through the legs

Iliac vein

Femoral artery carries blood to the legs

Femoral vein carries blood from the legs back to the heart

Saphenous vein is the body's longest blood vessel, running from the big toe to the groin and containing up to 20 valves

Tibial artery in the calf

Tibial vein

STATS AND FACTS

BLOOD DISTRIBUTION

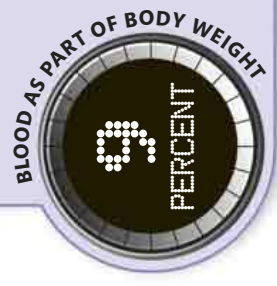


BLOOD VOLUME

9-11 pints
(5-6 liters) Amount of blood in an adult male, about the same as



24X MEASURING CUP



BODY PUMP

The heart

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.

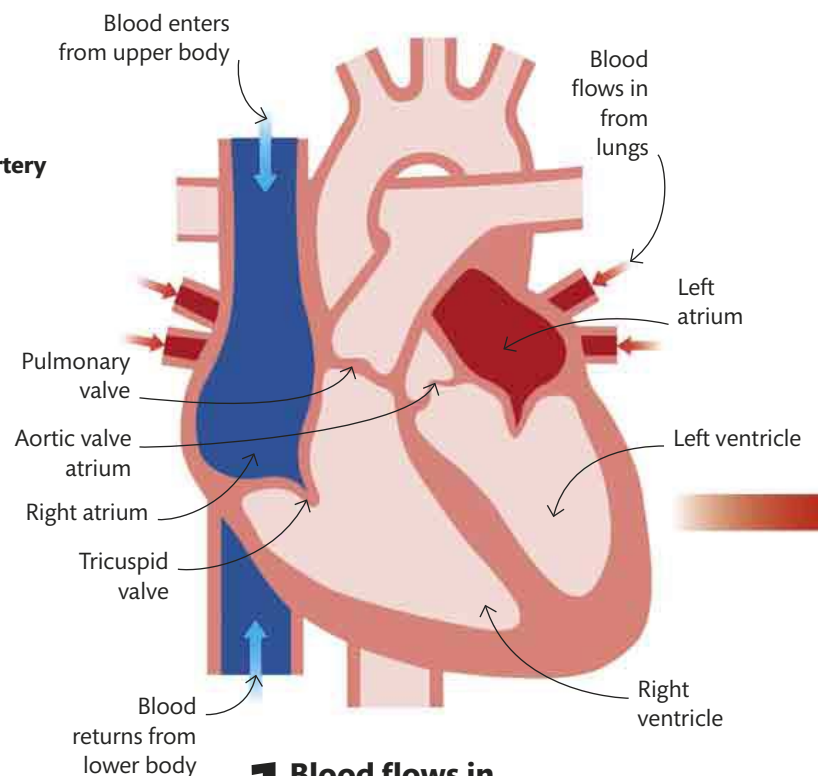
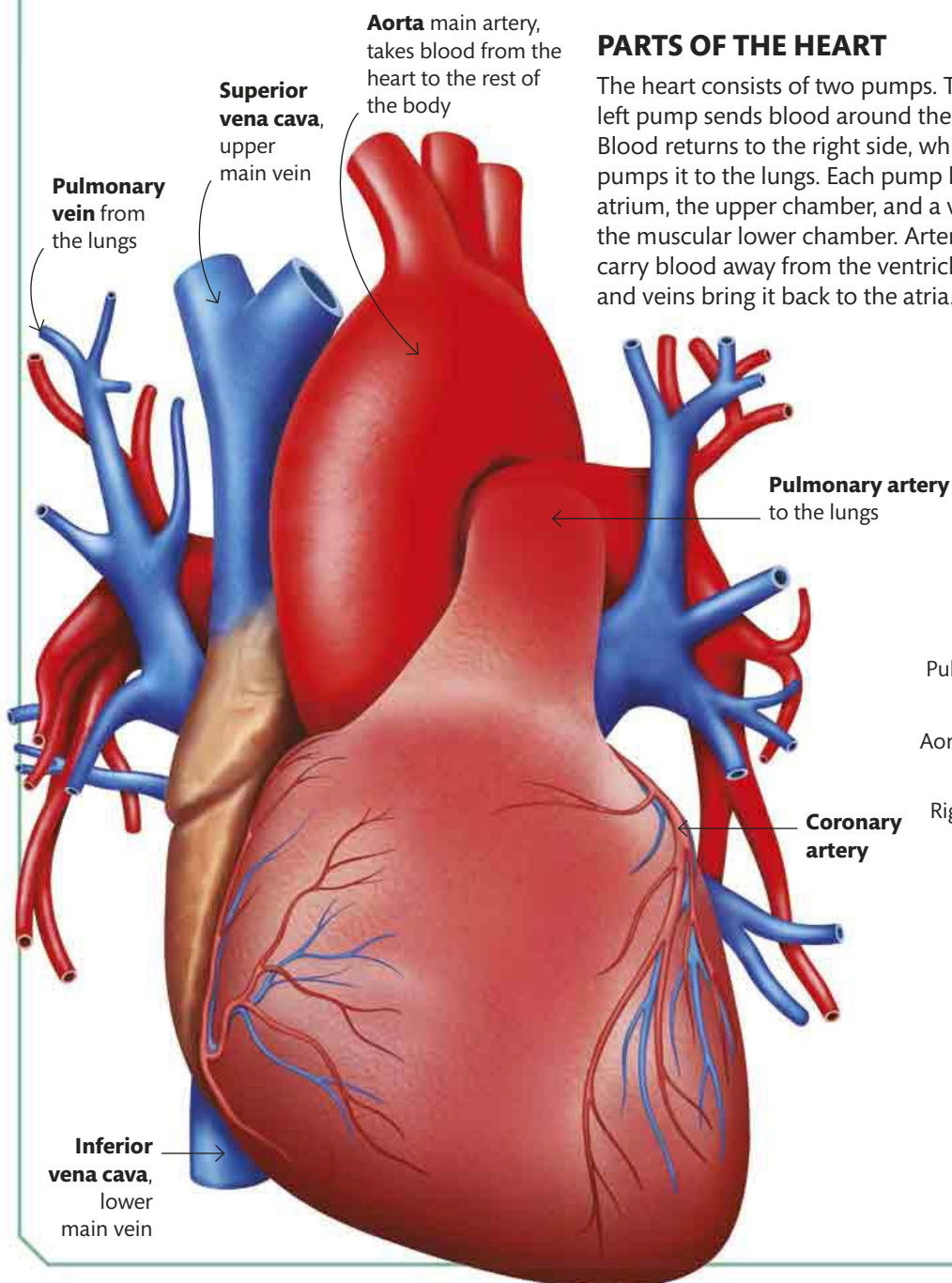
"Each day the heart creates energy that could power a truck for 20 miles (32 km)"

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.

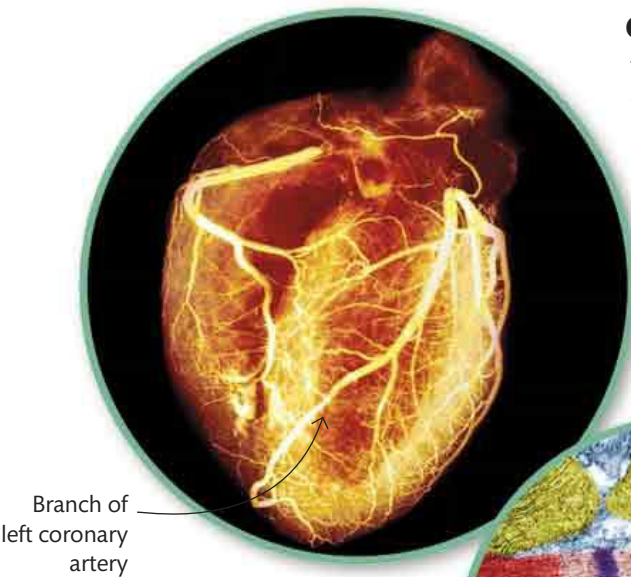
HOW THE HEART BEATS

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

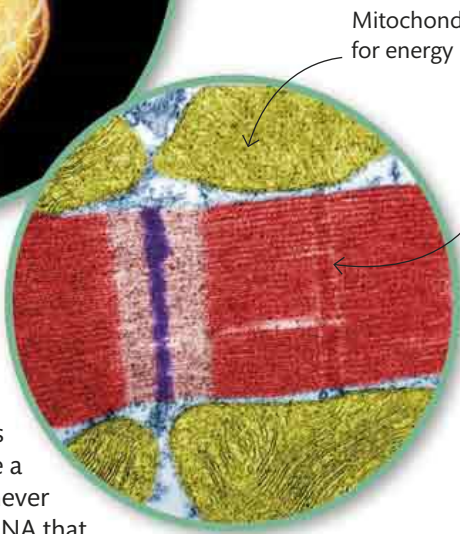
As the heart's muscular walls relax, blood oozes at low pressure from the main veins into the upper chambers (atria). Blood from the body, containing little oxygen, enters the right atrium. Blood carrying oxygen from the lungs enters the left atrium, through the pulmonary veins.



Branch of left coronary artery

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.



Mitochondria for energy

Thick muscle fiber

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

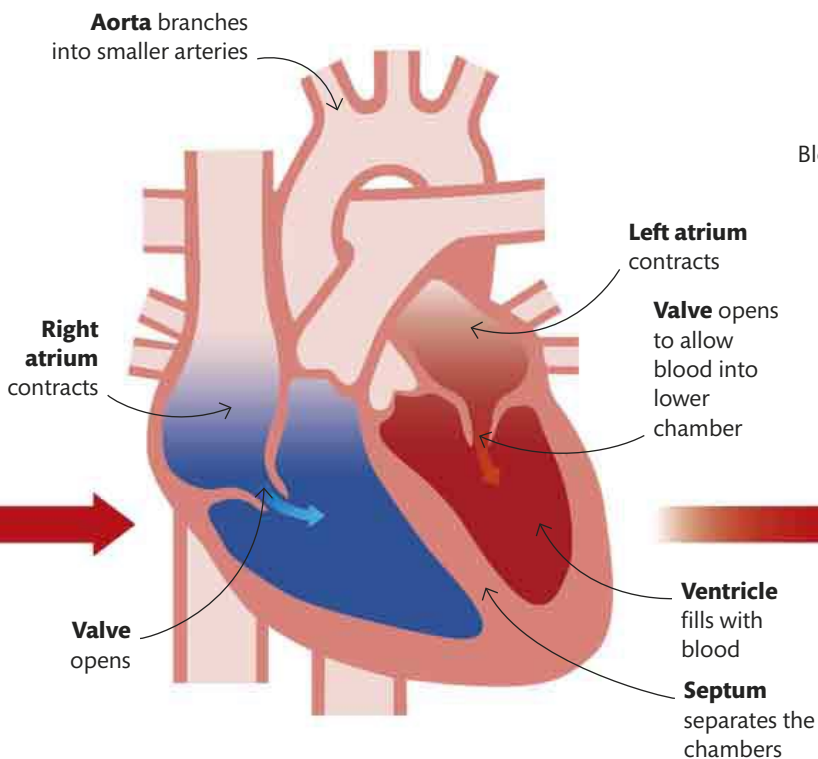
RESTING HEART RATE



HEART RATE (in bpm)

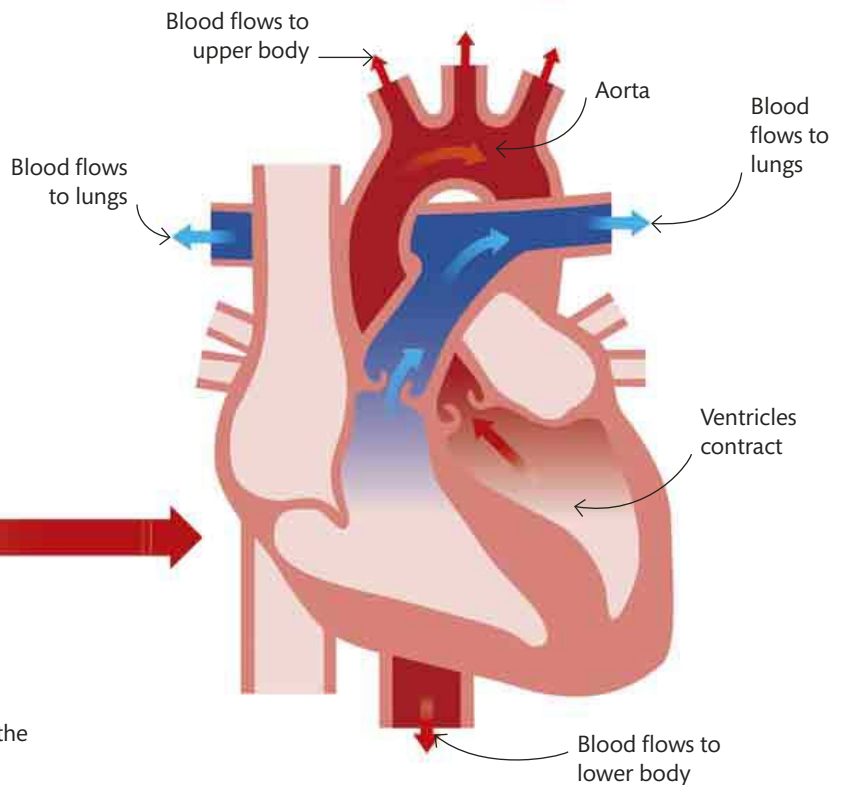


THE HEART BEATS 100,000 TIMES PER DAY



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

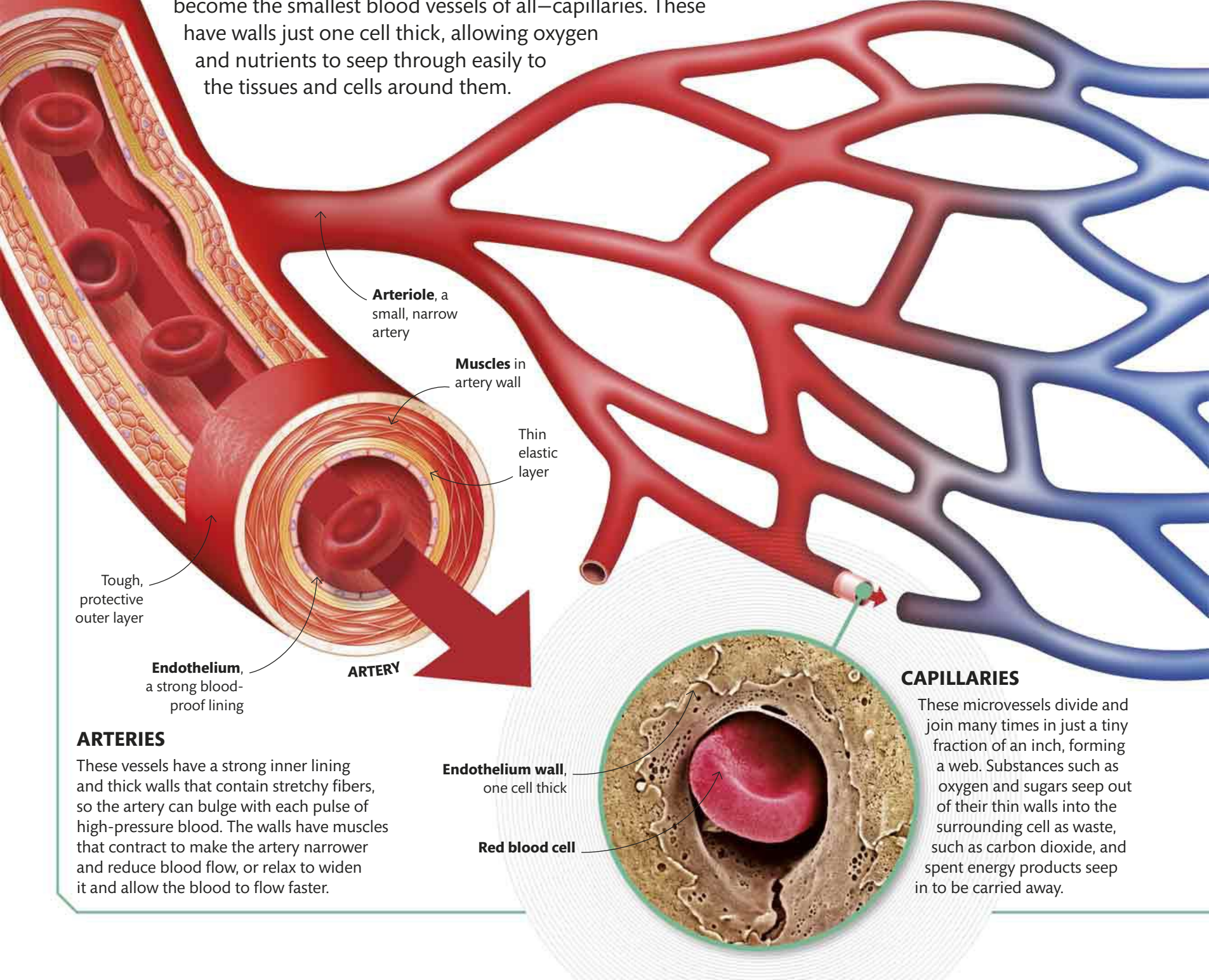
The muscular walls of the ventricles squeeze to force blood through valves into the arteries. The aorta (main artery) takes blood rich in oxygen from the left ventricle to the body, while the pulmonary arteries from the right ventricle carry blood with low oxygen levels to the lungs.

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.



Arteriole, a small, narrow artery

Muscles in artery wall

Thin elastic layer

Tough, protective outer layer

Endothelium, a strong blood-proof lining

ARTERY

ARTERIES

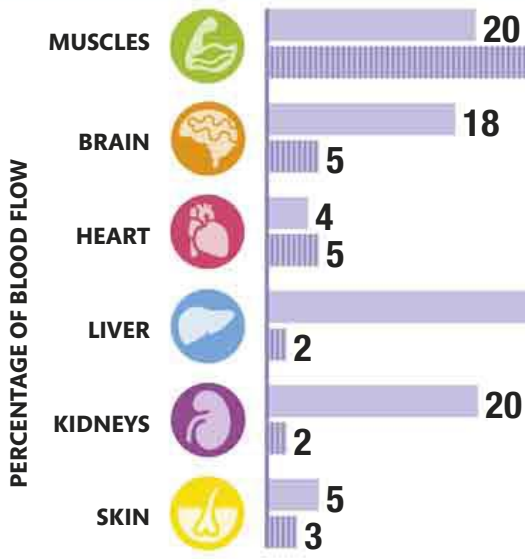
These vessels have a strong inner lining and thick walls that contain stretchy fibers, so the artery can bulge with each pulse of high-pressure blood. The walls have muscles that contract to make the artery narrower and reduce blood flow, or relax to widen it and allow the blood to flow faster.

Endothelium wall, one cell thick

Red blood cell

CAPILLARIES

These microvessels divide and join many times in just a tiny fraction of an inch, 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.

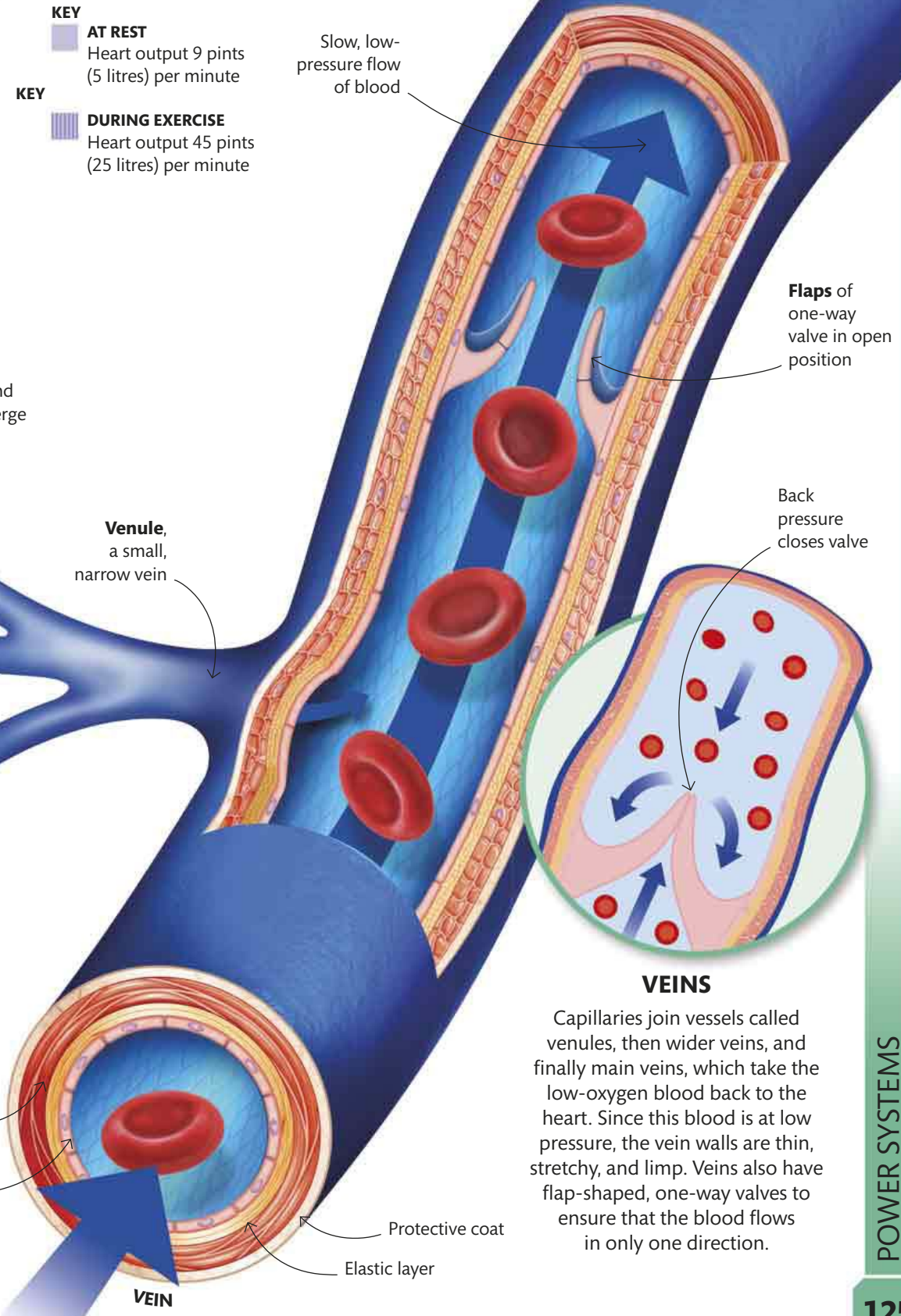
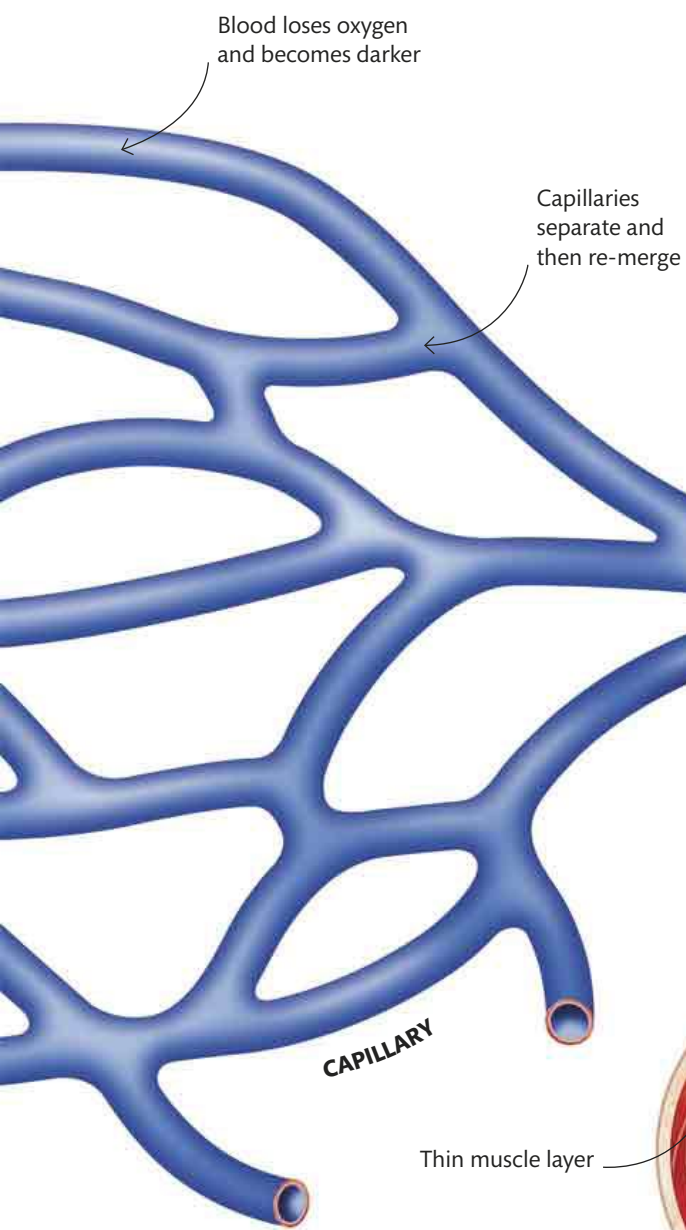


VARIED DEMANDS

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 9 pints (5 litres) per minute

KEY
DURING EXERCISE
 Heart output 45 pints (25 litres) 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 balloonlike 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 toward 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

4g

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 300 miles (400 km) 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 goey.

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 hemoglobin than people who live at lower levels. The chest, including the lungs and heart, is larger. More hemoglobin and a larger chest help people get as much oxygen from the air as possible.



Red cells

contain a substance called hemoglobin, which attaches to oxygen and carries it from the lungs to all body parts. Their average lifespan is 3-4 months.

White cells

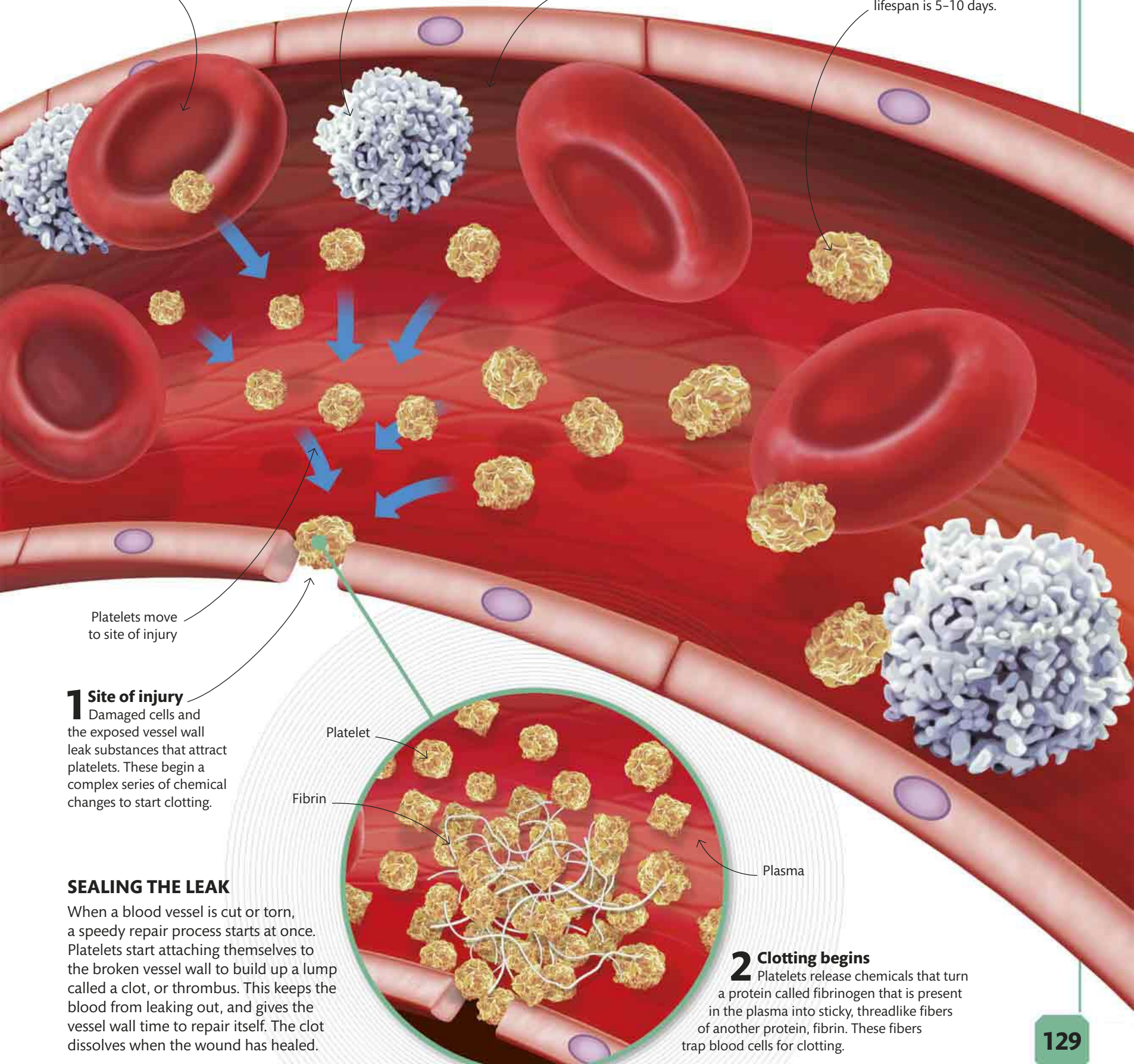
protect against germs and help in healing. These colorless cells are flexible, like water-filled plastic bags. Their lifespans range from a day to over a year.

Plasma

is around 95 percent water. There are more than 500 substances dissolved in it, including body salts, minerals, and nutrients.

Platelets

are smaller than red or white cells. Platelets are usually rounded but become spiky when they form blood clots. Their lifespan is 5-10 days.



Platelets move to site of injury

1 Site of injury

Damaged cells and the exposed vessel wall leak substances that attract platelets. These begin a complex series of chemical changes to start clotting.

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 keeps the blood from leaking out, and gives the vessel wall time to repair itself. The clot dissolves when the wound has healed.

2 Clotting begins

Platelets release chemicals that turn a protein called fibrinogen that is present in the plasma into sticky, threadlike fibers of another protein, fibrin. These fibers trap blood cells for clotting.

CLIMBING HIGH

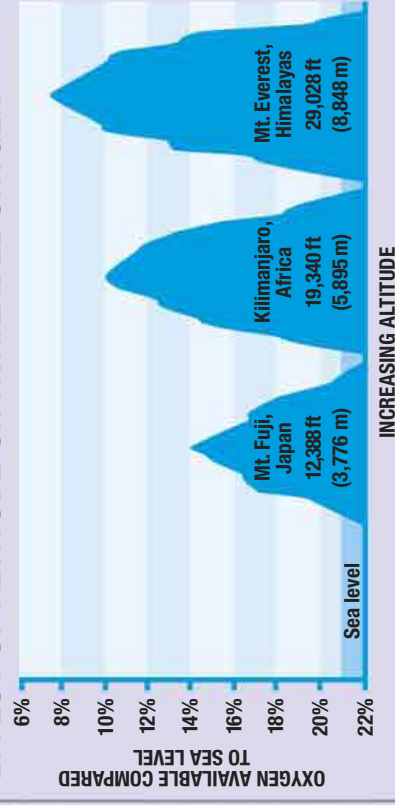
Oxygen levels

Higher air is thinner air—and the lack of oxygen and lower air pressure can leave you gasping for breath. At 9,900 ft (3,000 m), 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 13,000 ft (4,000 m), one in two. It is best to climb up around 1,600 ft (500 m) a day, which allows the body to gradually increase its red cells so that it can pick up more of the scarce oxygen.

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

STATS AND FACTS

EFFECT OF ALTITUDE ON AVAILABLE OXYGEN





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, hemoglobin, 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

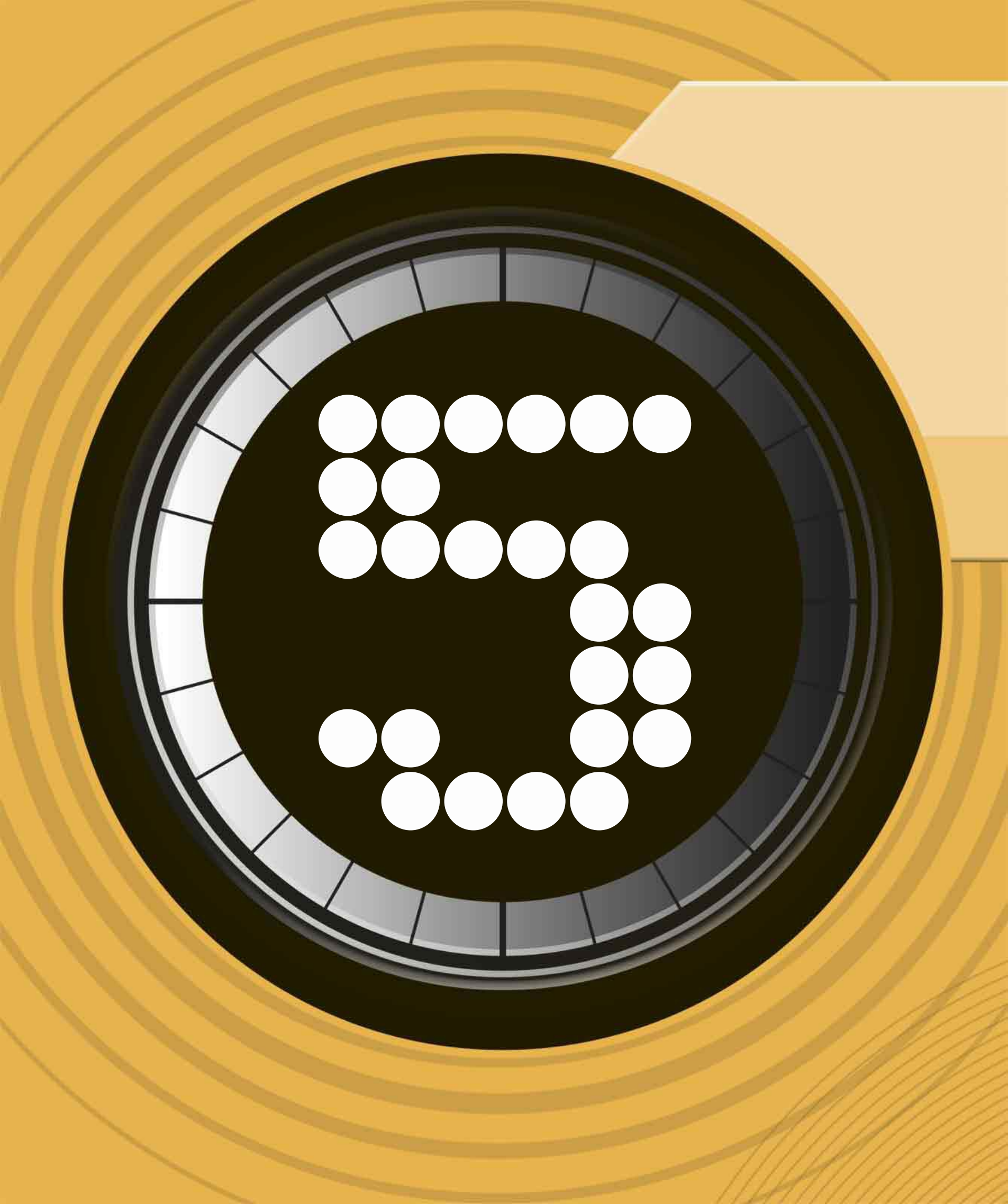
red blood cells would cover
a distance of $\frac{1}{8}$ in (1 cm)



**“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 threadlike 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.



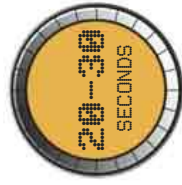
FUEL AND WASTE

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.

FUELING THE BODY

How digestion works

As chewed food slips down the gullet toward 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.



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 30 FT (9 M)
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 fibers.

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 fibers. 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.

Fiber

Present in all fruits and vegetables, fiber 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

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



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



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



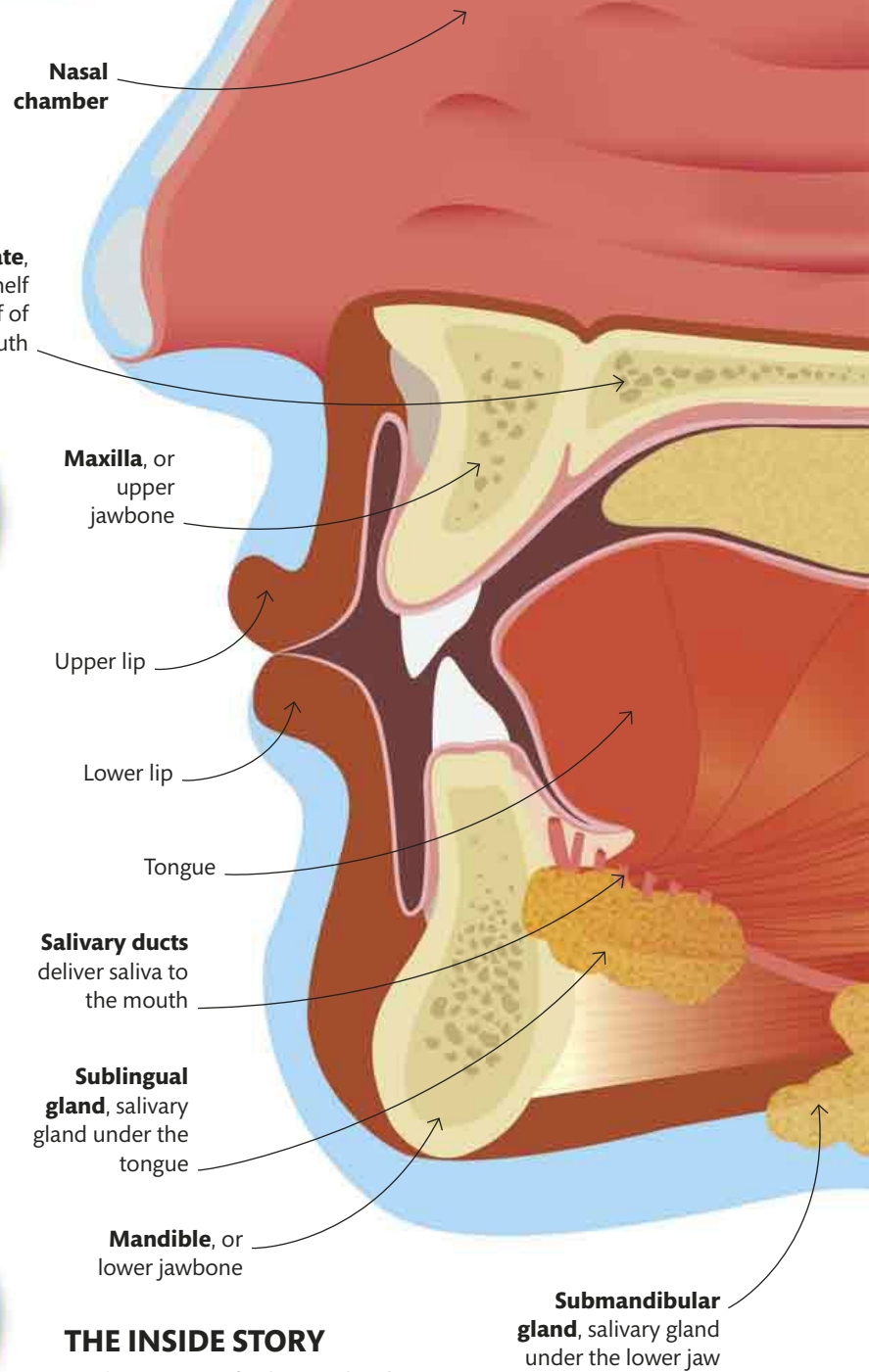
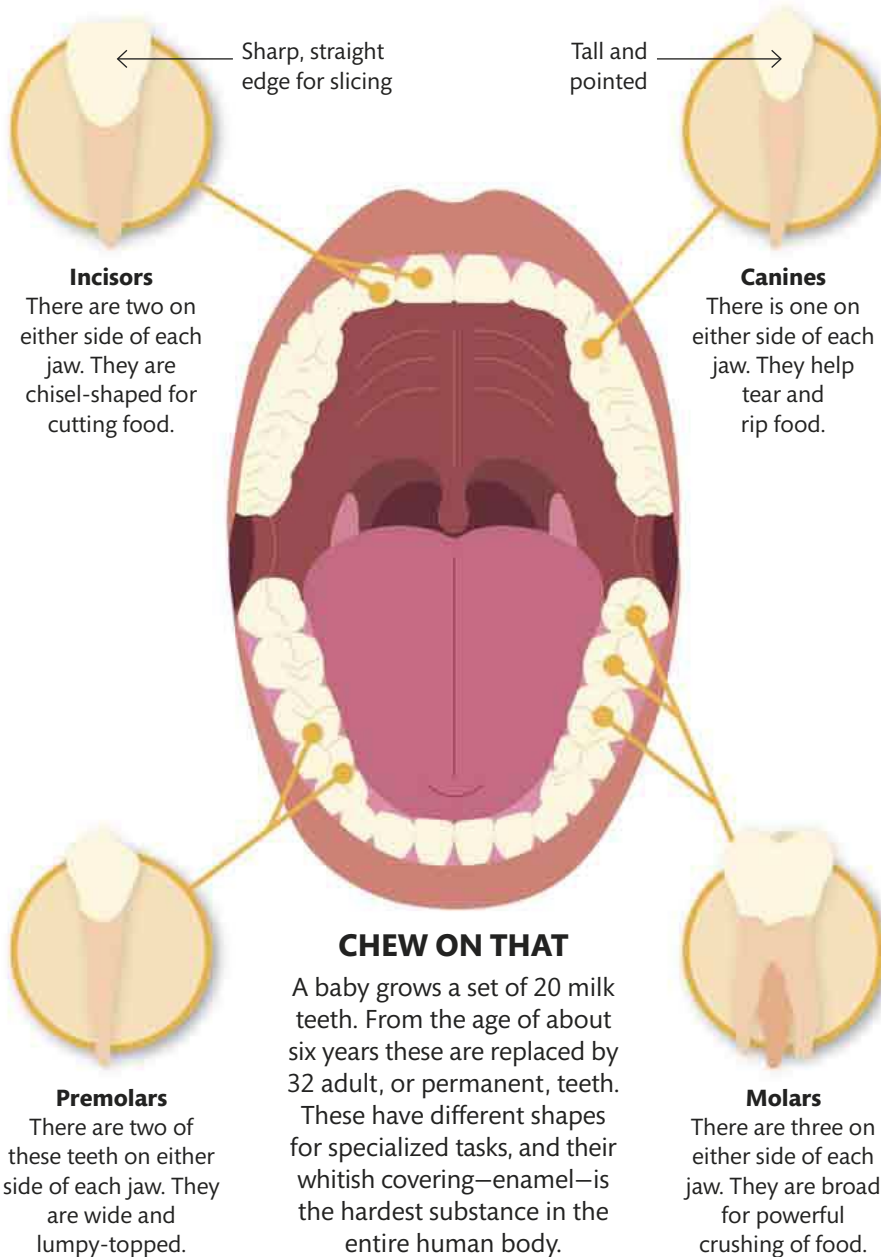
DIGESTION IN ACTION

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.



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 backward down the throat.

STATS AND FACTS

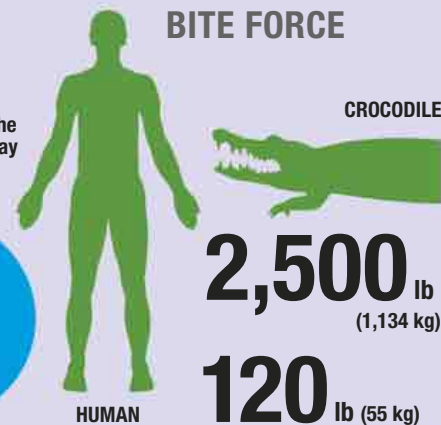
SALIVA FACTS

2 pints (1 liter)
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.



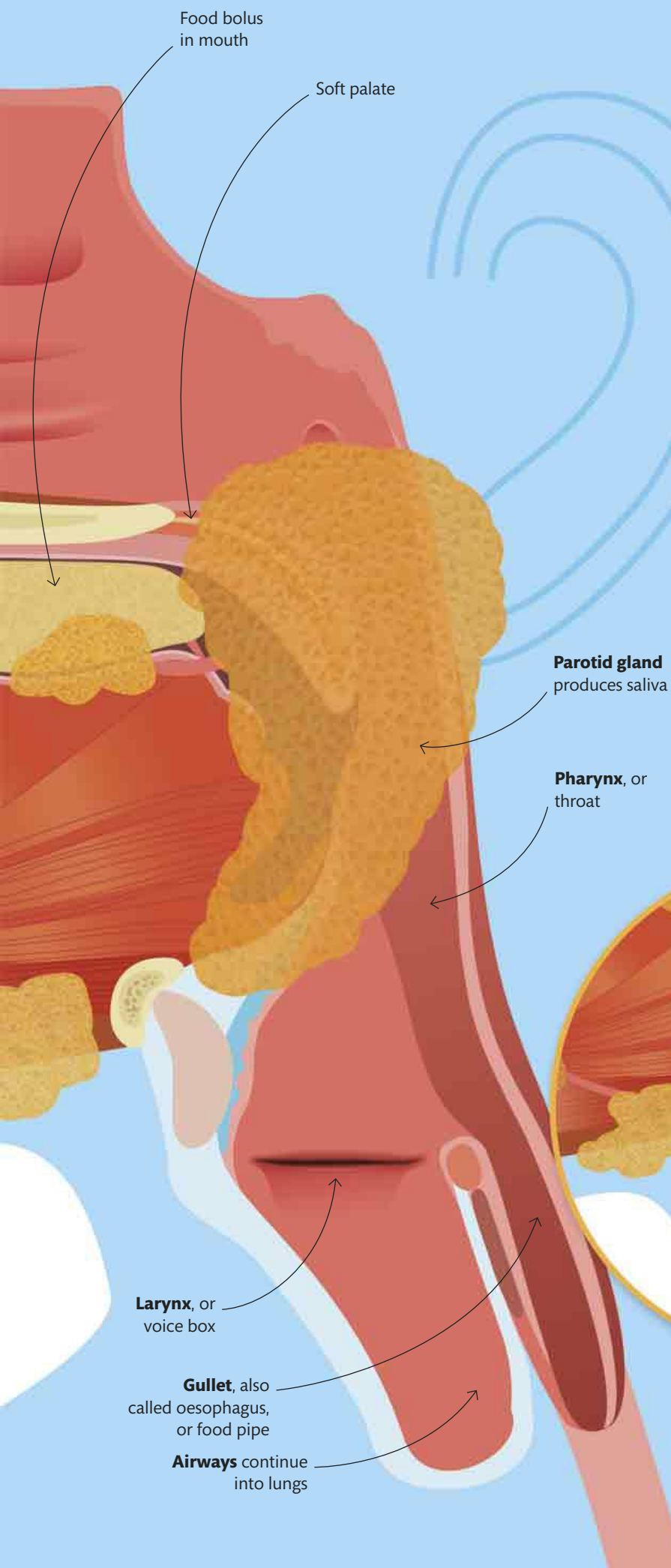
BITE FORCE



“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. This process of squeezing food along is called peristalsis. As each lump slides down, it bends a flap of cartilage, called the epiglottis, closing off the windpipe to prevent choking.



Parotid gland produces saliva

Pharynx, or throat

Larynx, or voice box

Gullet, also called oesophagus, or food pipe

Airways continue into lungs

Epiglottis tilts to cover windpipe

Bolus, or lump of food

ACID BATH

Inside the stomach

An **empty stomach** is smaller than a clenched fist, folded and shriveled, while a full one—stretched tight like a balloon—can be almost soccer-ball-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

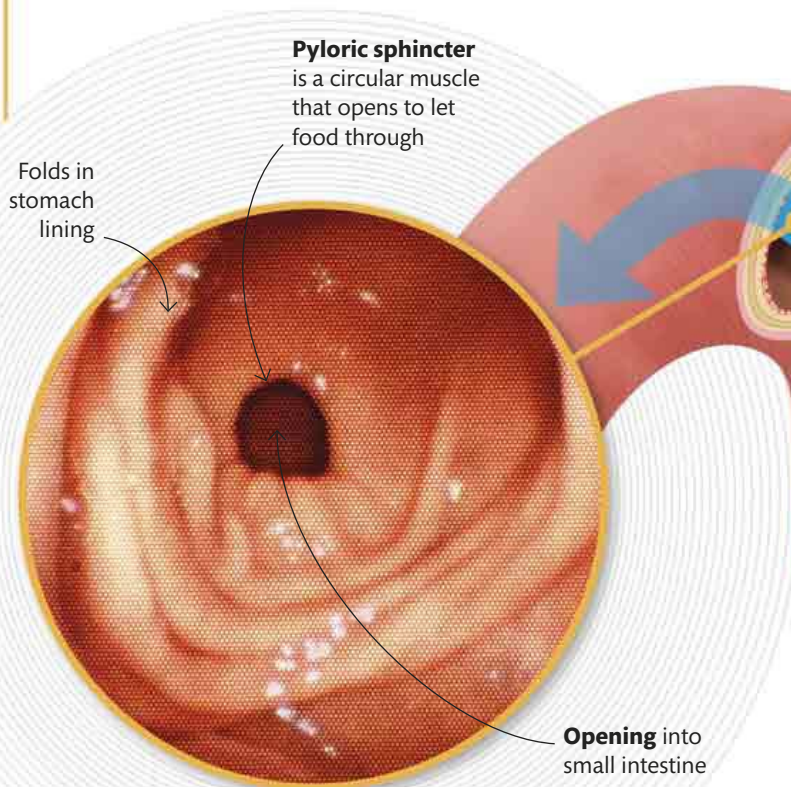
The thick stomach wall has three layers of muscles that lie in different directions from each other. These muscles contract in waves making the stomach long and thin, short and wide, or almost any other shape, to mix and mash the meal.

1 Chewed food enters through the valvelike esophageal 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.

Gastric pits are like small pockets in the stomach lining

Hydrochloric acid and digestive enzymes pour in from the pits



Pyloric sphincter is a circular muscle that opens to let food through

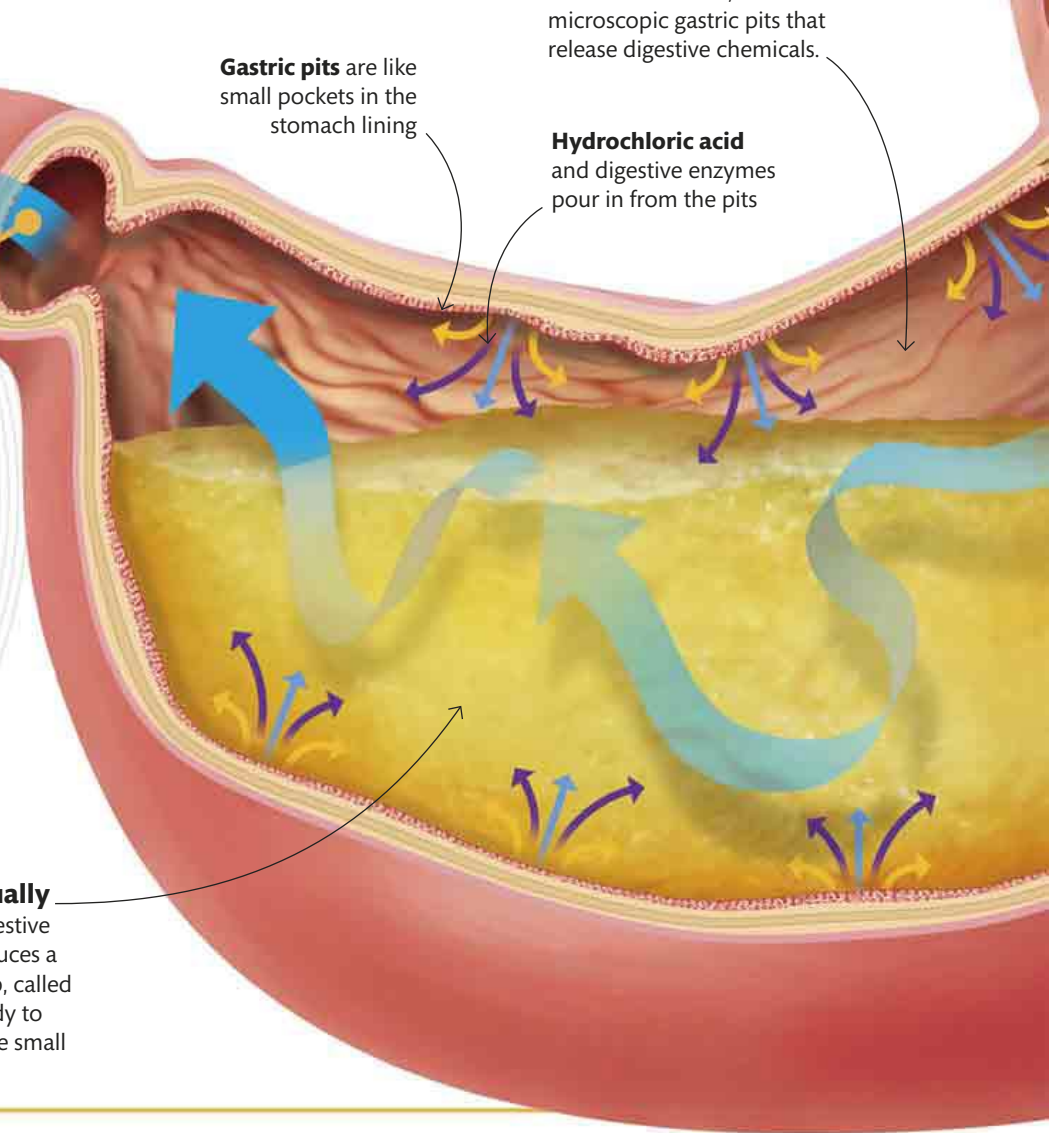
Folds in stomach lining

Opening into small intestine

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 13 feet (4 meters)

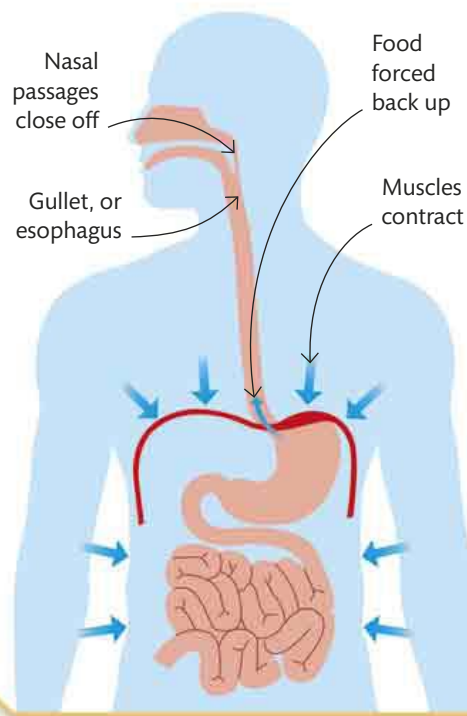
Longitudinal muscle layer

Circular muscle layer

Diagonal muscle layer

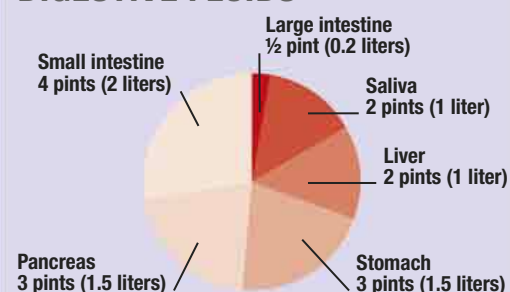
UP IT COMES

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.



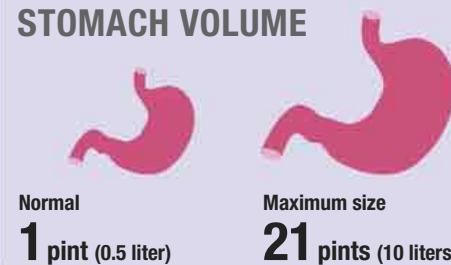
STATS AND FACTS

DAILY PRODUCTION OF DIGESTIVE FLUIDS



95% of water in the digestive system is recycled

STOMACH VOLUME



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)



2–3

Citric acid

LEMON JUICE

WEAK



1–2

Hydrochloric acid

STOMACH ACID



0.8–1

Sulfuric acid

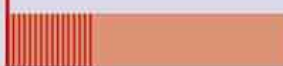
CAR BATTERY

STRONG

AVERAGE THICKNESS



1/5 in (5 mm)
Whole stomach wall



1/16 in (1.5 mm)
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”



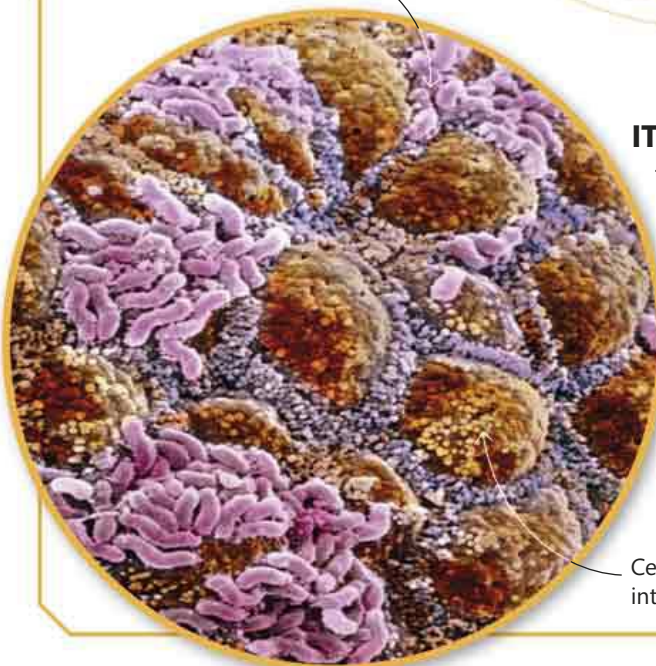
GUT REACTIONS

Inside the intestines

A few hours after a meal, globs of smelly, soupy, and partly 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 in 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 2 pints (1 liter) of gas every day”

Rod-shaped bacteria multiply constantly



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.

Cells of intestinal lining

TWISTS AND TURNS

The small intestine is more than 20 ft (6 m) long but only 1¼ in (3 cm) wide and has many bends, folds, and coils. It leads into the first part of the large intestine, called the cecum, which connects to the colon. The large intestine loops around the small intestine and is 5 ft (1.5 m) long (about the length of a bicycle) and 2¾ in (7 cm) 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, fingerlike projections called villi. The villi increase the surface area of the gut, helping nutrients to be absorbed more rapidly.

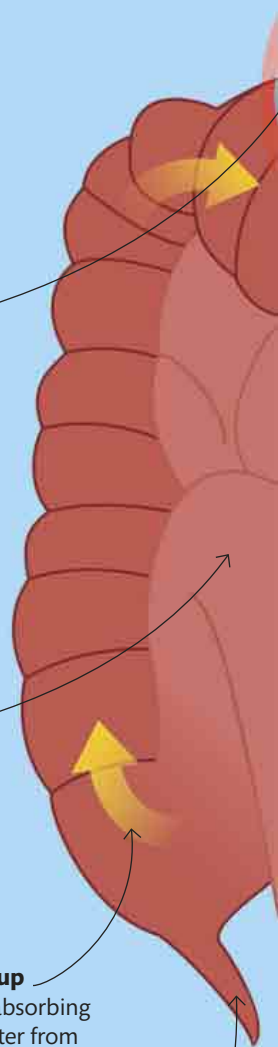
3 Soaking it up

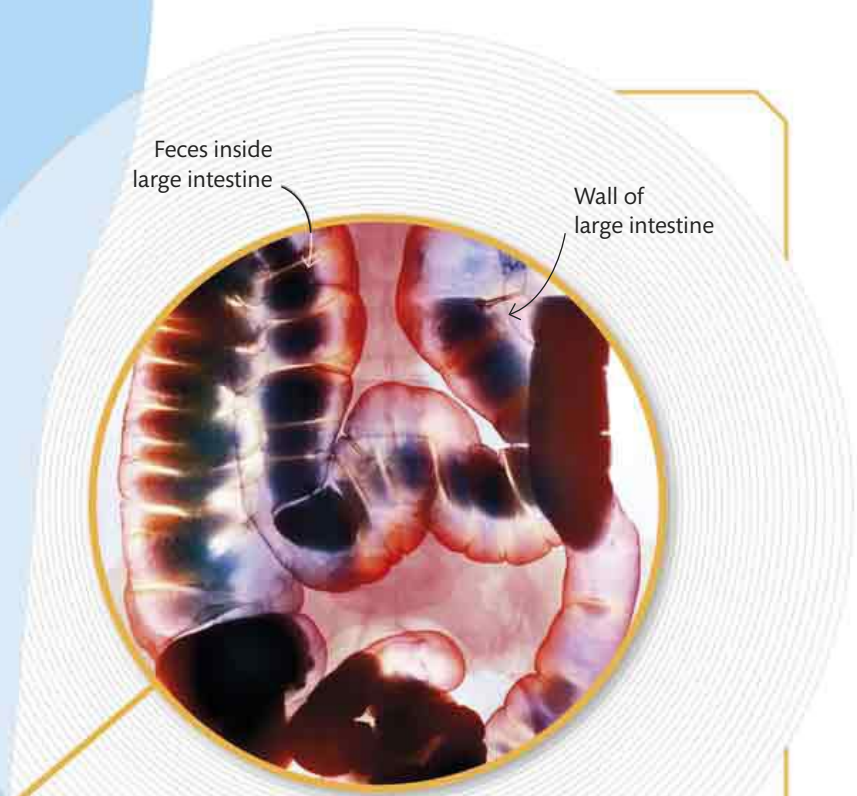
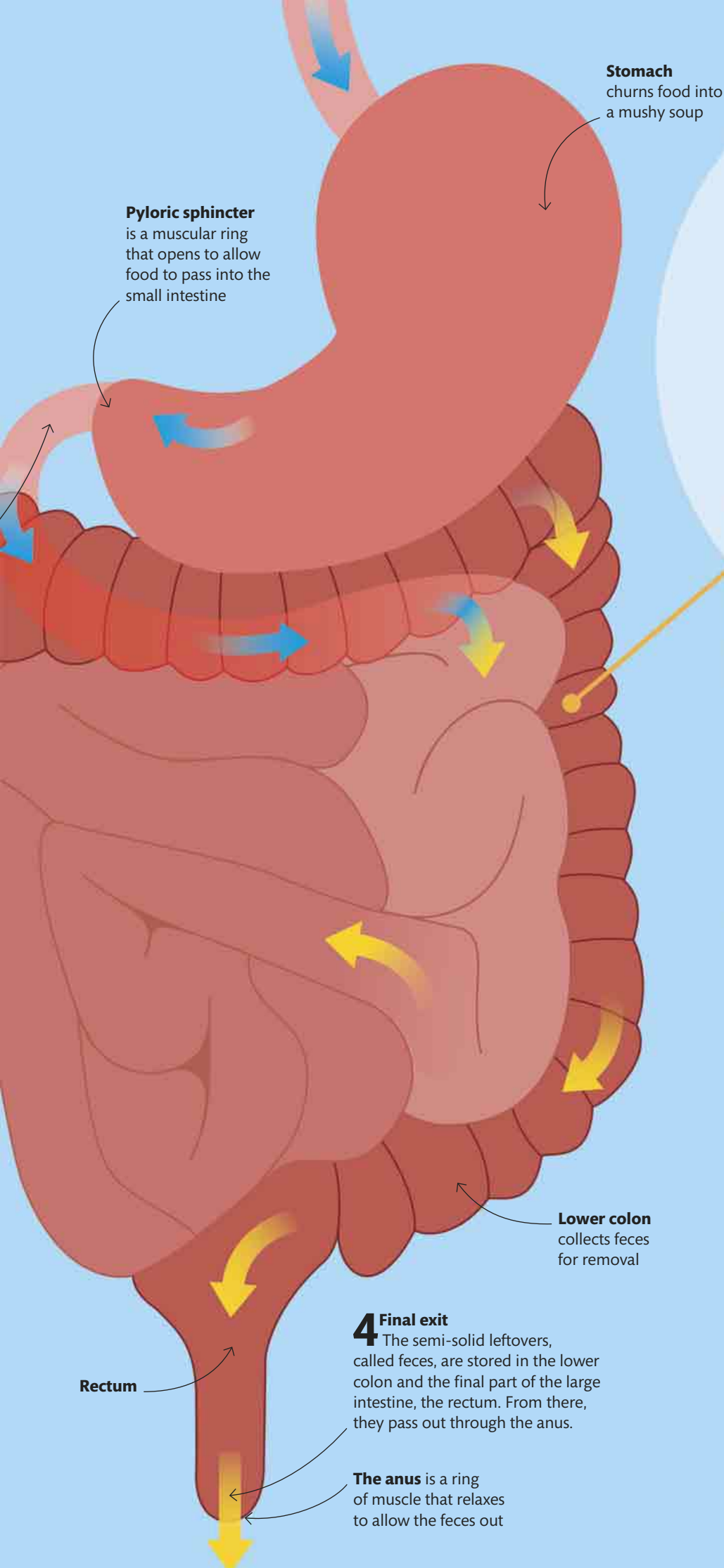
As well as absorbing most of the water from the undigested leftovers through its lining, the large intestine absorbs body salts and minerals such as sodium.

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



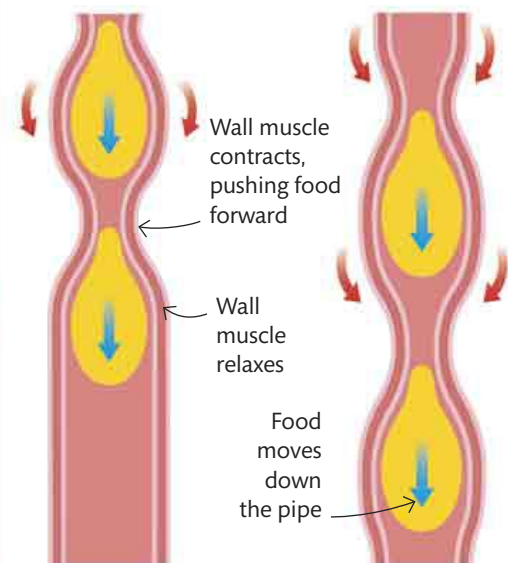


END OF THE LINE

When the food has been broken down, what is left is a mixture of insoluble fiber 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, wavelike motion called peristalsis. This is created by muscles in the passage walls, which contract with a squeezing action that pushes the food ahead.



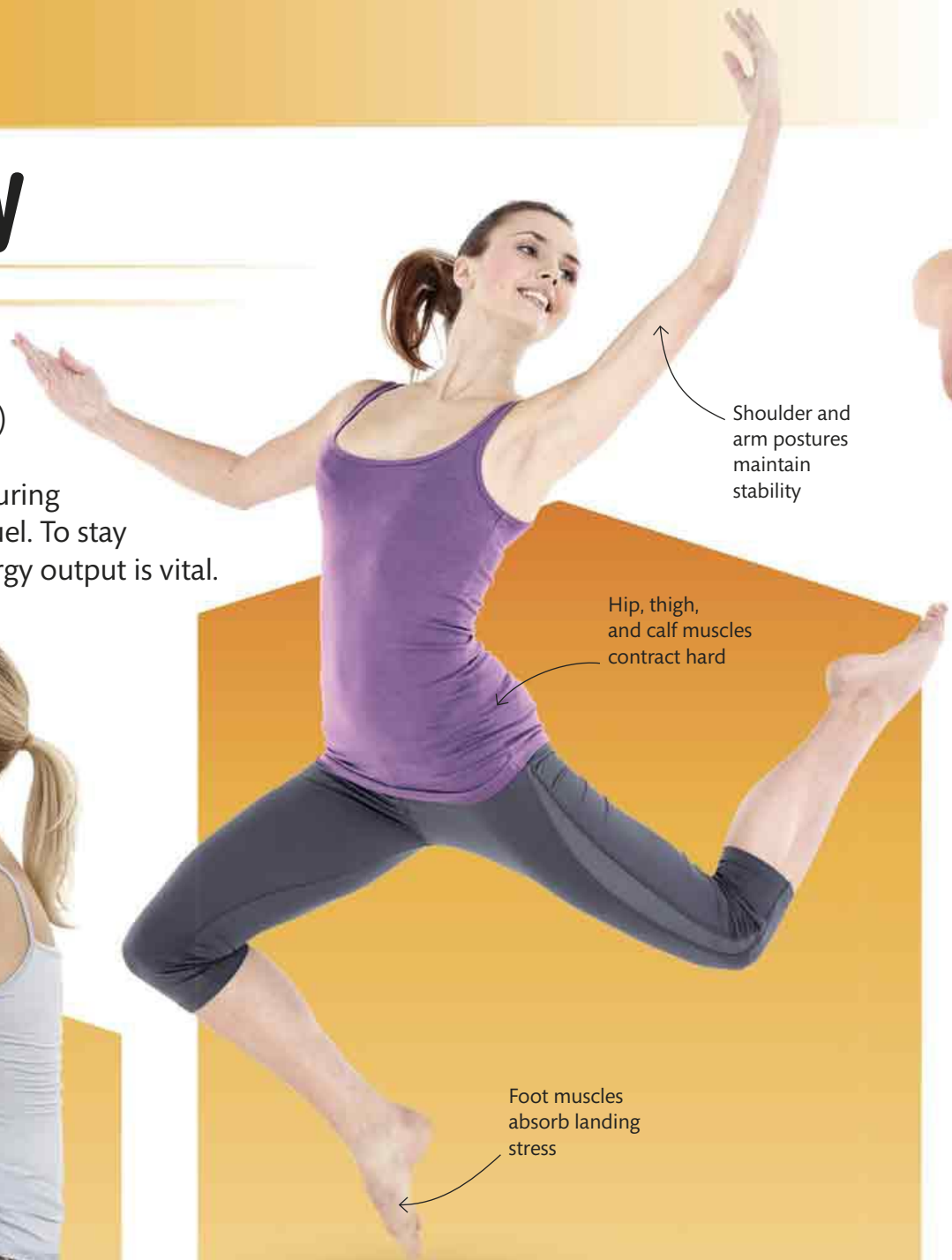
FUEL UP!

Food as energy

You are a powerhouse of energy use. At maximum output, such as when sprinting, the body consumes more than 20 Calories (kcal) 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.



Shoulder and arm postures maintain stability

Hip, thigh, and calf muscles contract hard

Foot muscles absorb landing stress

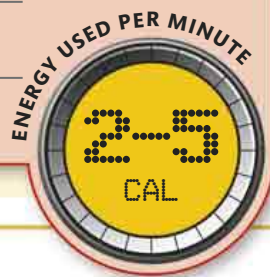
Relaxed legs reduce energy use



LOW LEVEL

Lying flat requires the least energy because most muscles can relax, so they need energy only 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 relaxed, torso and neck maintain balance
- **STANDING** Leg, torso, and neck muscles continually shift to maintain balance
- **SLOW WALKING** Leaning forward slightly gives momentum to save some energy



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.

- **BICYCLING** 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





Wide range of arm movements

Torso twists and bends

Thigh and buttock muscles work hip and knee hard

Calf muscles twist foot for direction change

MAXIMUM LEVEL

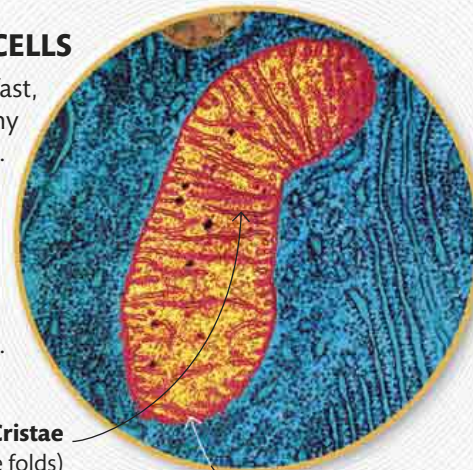
During strenuous activity almost every muscle works hard to move the body and its parts, to maintain posture and balance. Up to one-fifth of the energy used by some muscles is for contracting against other muscles, to ensure smooth coordination and prevent jerks.

- **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



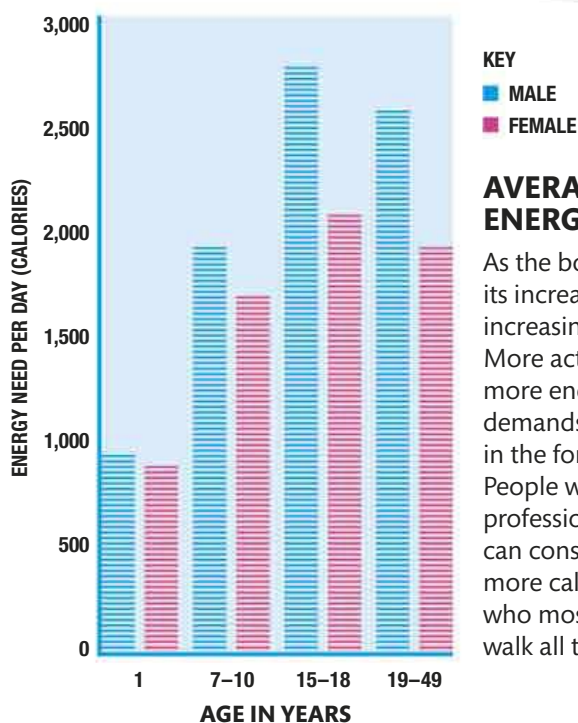
FUEL CELLS

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.



Cristae (shelflike folds)

Outer membrane



KEY

- MALE
- FEMALE

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 calories than people who mostly sit, stand, or walk all through the day.

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 Calories (kcal) while 1 g of carbohydrate contains 4 Calories (kcal). Some fat stays in the body as a vital store of energy. Fruits and vegetables contain less energy, but provide essential vitamins, minerals, and fiber.

300 CALORIES =



4 APPLES

1 BURGER

1/4 PIZZA

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.

“Running a marathon uses as much energy as is contained in 12 slices of pizza”

STATS AND FACTS

CALORIES USED



BICYCLING

24 Calories/mile
(15 kcal/km)



WALKING

80–97 Calories/mile
(50–60 kcal/km)



RUNNING

97–129 Calories/mile
(60–80 kcal/km)



SWIMMING

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

DAILY ENERGY



MAN

2,500
Calories (kcal)



ULTRA-ATHLETE

4,700
Calories (kcal)



POLAR EXPLORER

7,000+
Calories (kcal)



Defying the dunes

Competitors in the Sahara ultra-marathon have to cover 155 miles (250 km) of desert in six days. With temperatures above 104°F (40°C), 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.



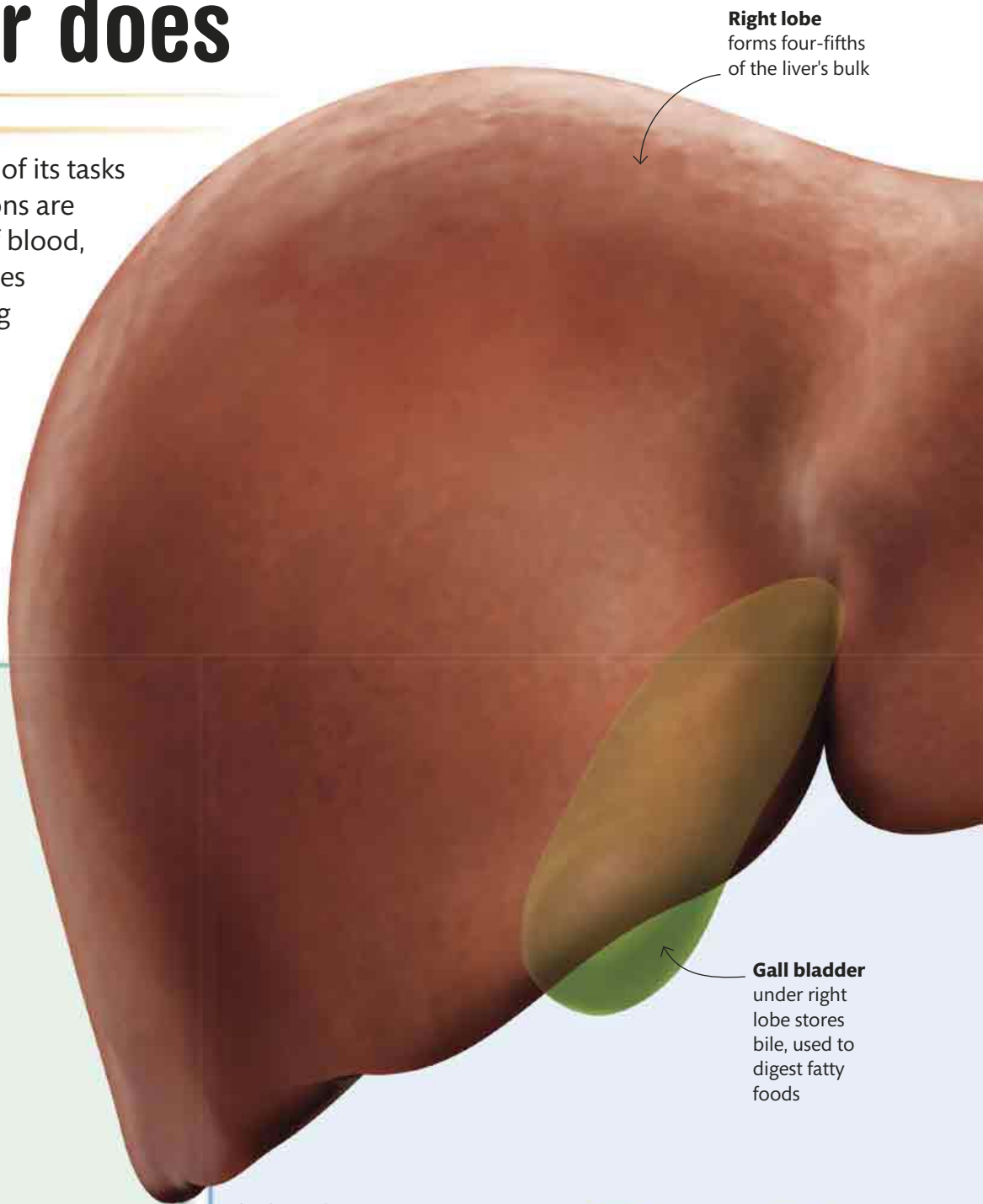
Blood cells

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.



Right lobe
forms four-fifths
of the liver's bulk

Gall bladder
under right
lobe stores
bile, used to
digest fatty
foods

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

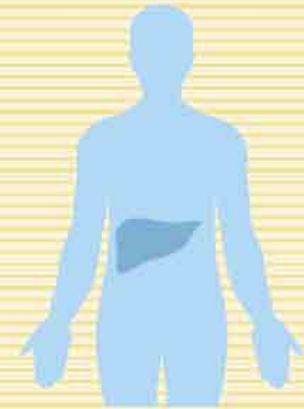
These include iron needed for blood cells and copper for bones and connective tissues.

“The liver performs around 500 functions”



Left lobe
arches over
stomach

AT A GLANCE



- **SIZE** Length 9½–10 in (24–26 cm); height 2¾–3 in (7–8 cm); weight 3–4 lb (1.5–1.7 kg)
- **LOCATION** Almost fills the upper abdomen
- **FUNCTION** Stores many substances, regulates blood content, and breaks down toxins

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.



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.



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

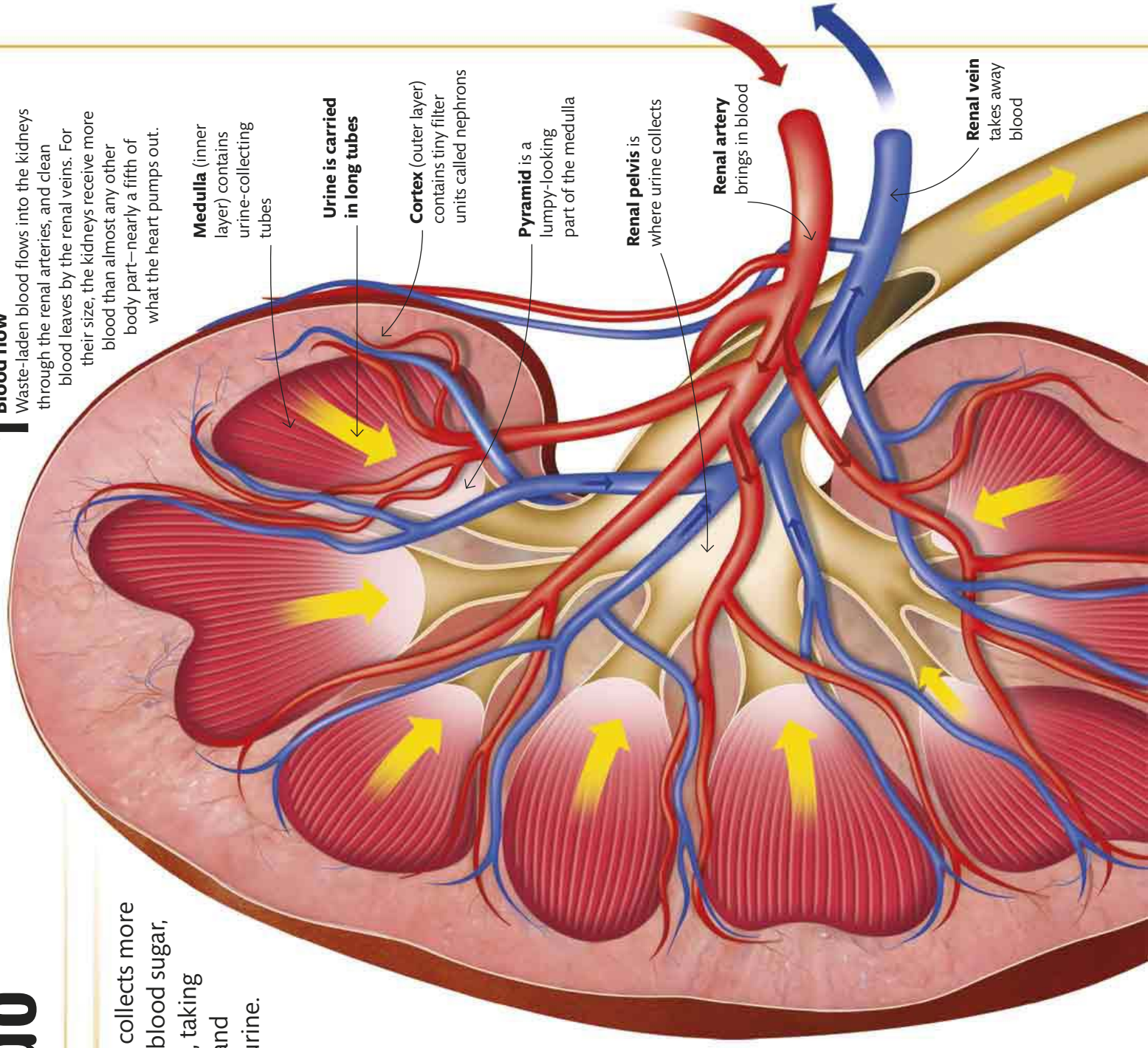
As blood flows past cells and through tissues, it collects more than 100 kinds of waste and any excess sodium, blood sugar, and water. Blood then travels to the two kidneys, taking five minutes to pass through them. Here, waste and excess substances are made into a liquid called urine. The urine trickles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

WASTE COLLECTION

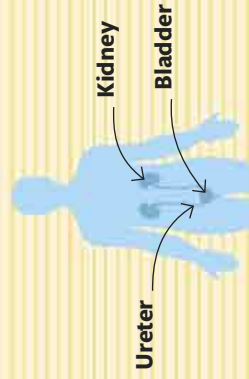
Inside its tough covering, each kidney is split into three layers: the outer cortex, the inner medulla, and a space called the renal pelvis. Urine is made in the cortex and carried by tubes into the renal pelvis. From here it flows along the ureter to the bladder.

1 Blood flow

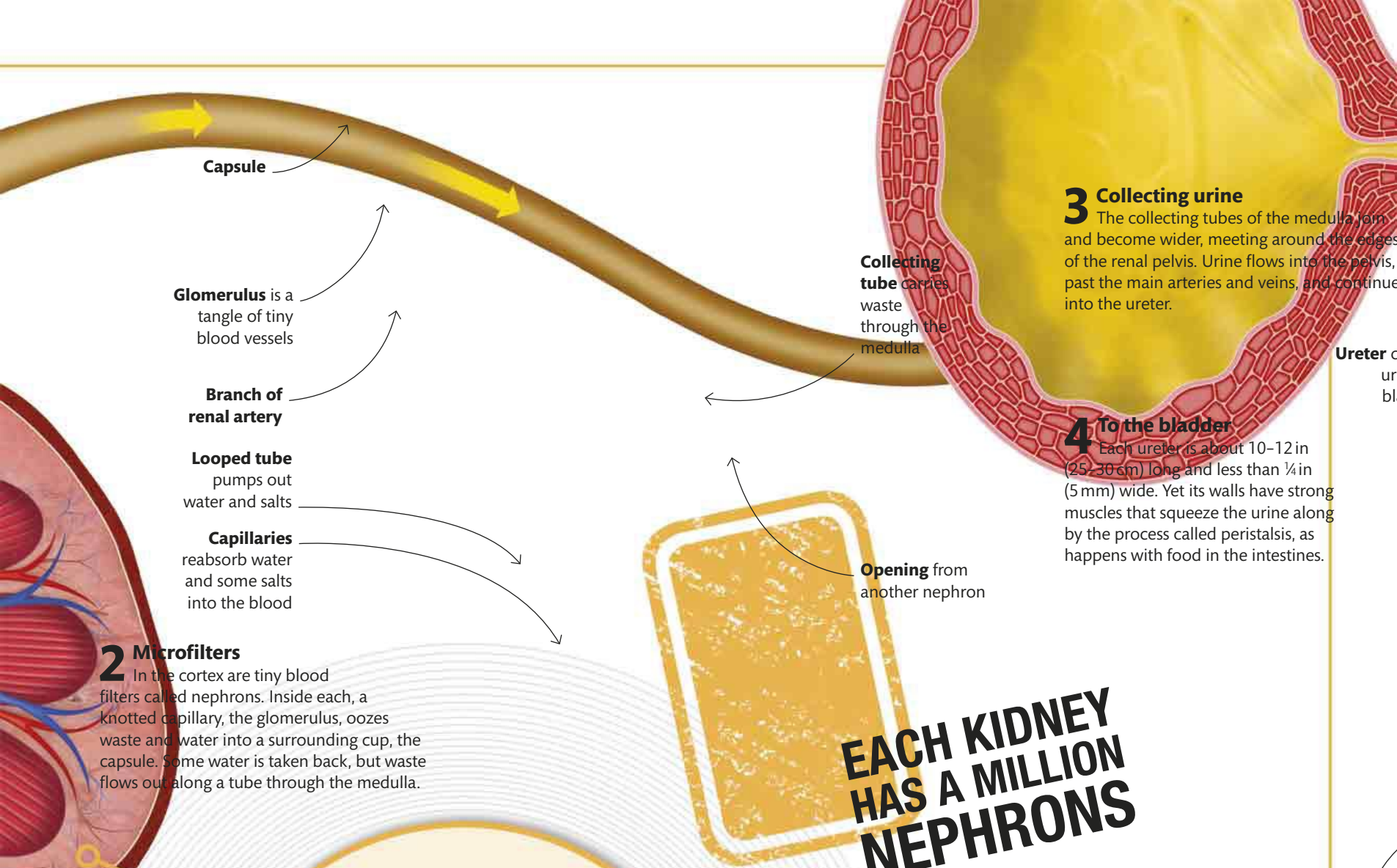
Waste-laden blood flows into the kidneys through the renal arteries, and clean blood leaves by the renal veins. For their size, the kidneys receive more blood than almost any other body part—nearly a fifth of what the heart pumps out.



AT A GLANCE



- **SIZE** Length of each kidney $4\frac{3}{4}$ in (12 cm); weight $5\frac{1}{4}$ oz (150 g); bladder 17 fl oz (500 ml) when full
- **LOCATION** Kidneys behind liver and stomach; bladder in lower front abdomen
- **FUNCTION** Kidneys filter wastes from blood, make hormones; bladder stores urine



Capsule

Glomerulus is a tangle of tiny blood vessels

Branch of renal artery

Looped tube pumps out water and salts

Capillaries reabsorb water and some salts into the blood

Collecting tube carries waste 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 10–12 in (25–30 cm) long and less than ¼ in (5 mm) wide. Yet its walls have strong muscles that squeeze the urine along by the process called peristalsis, as happens with food in the intestines.

Ureter carries urine to the bladder

Opening from another nephron

2 Microfilters

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.

EACH KIDNEY HAS A MILLION NEPHRONS

STATS AND FACTS

BLOOD CLEANSING

1
2
3
4
5
6

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

OLYMPIC SWIMMING POOL

BLADDER LENGTH

2 in
(5 cm)
when empty

4 ¾ in
(12 cm) or more
when full

WATER IN URINE

45 PERCENT

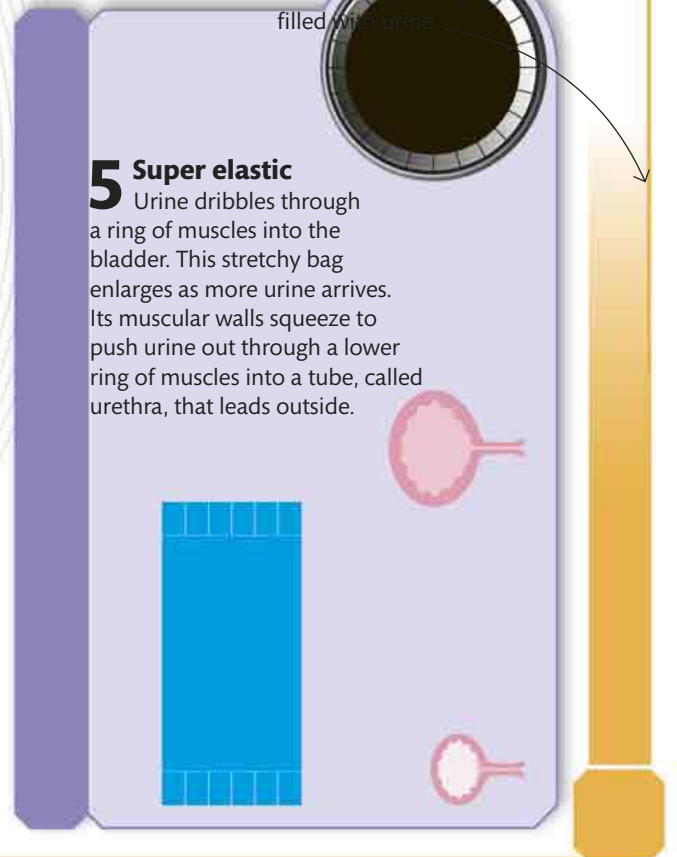
153

FUEL AND WASTE

Bladder filled with urine

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.





DEFENSE 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 defenses against these tiny invaders! Every organ, from the eyes to the guts, is equipped with physical and chemical barriers to protect it from harm. There are two systems that specialize in self-defense—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.

Nose hairs and mucus trap dust and germs

Saliva (spit) traps and removes germs

Adenoids trap and kill eaten or inhaled germs

Thymus gland, where white cells mature into germ killers

Spleen stores and recycles blood cells

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.

WE HAVE AROUND 650 LYMPH NODES





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)

Lymph fluid renews daily



Red blood cells

BONE MARROW

As well as making new red cells, the jellylike 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.

Valve allows lymph to move in only one direction

White blood cells are concentrated here

Vessel carries lymph away from node

LYMPH NODES

These small, beanlike 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.

STATS AND FACTS

RATE OF FLOW



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

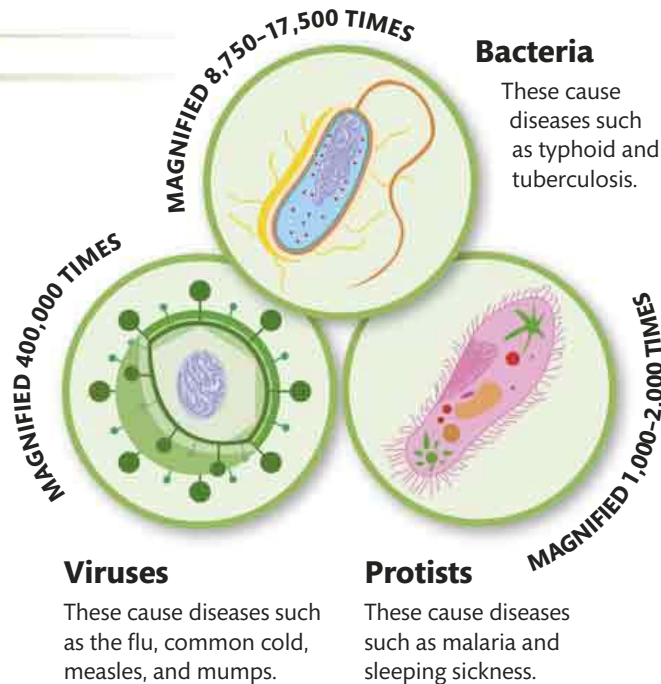
Combating germs

Despite the body's super-tough defense 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!

GERM WARFARE

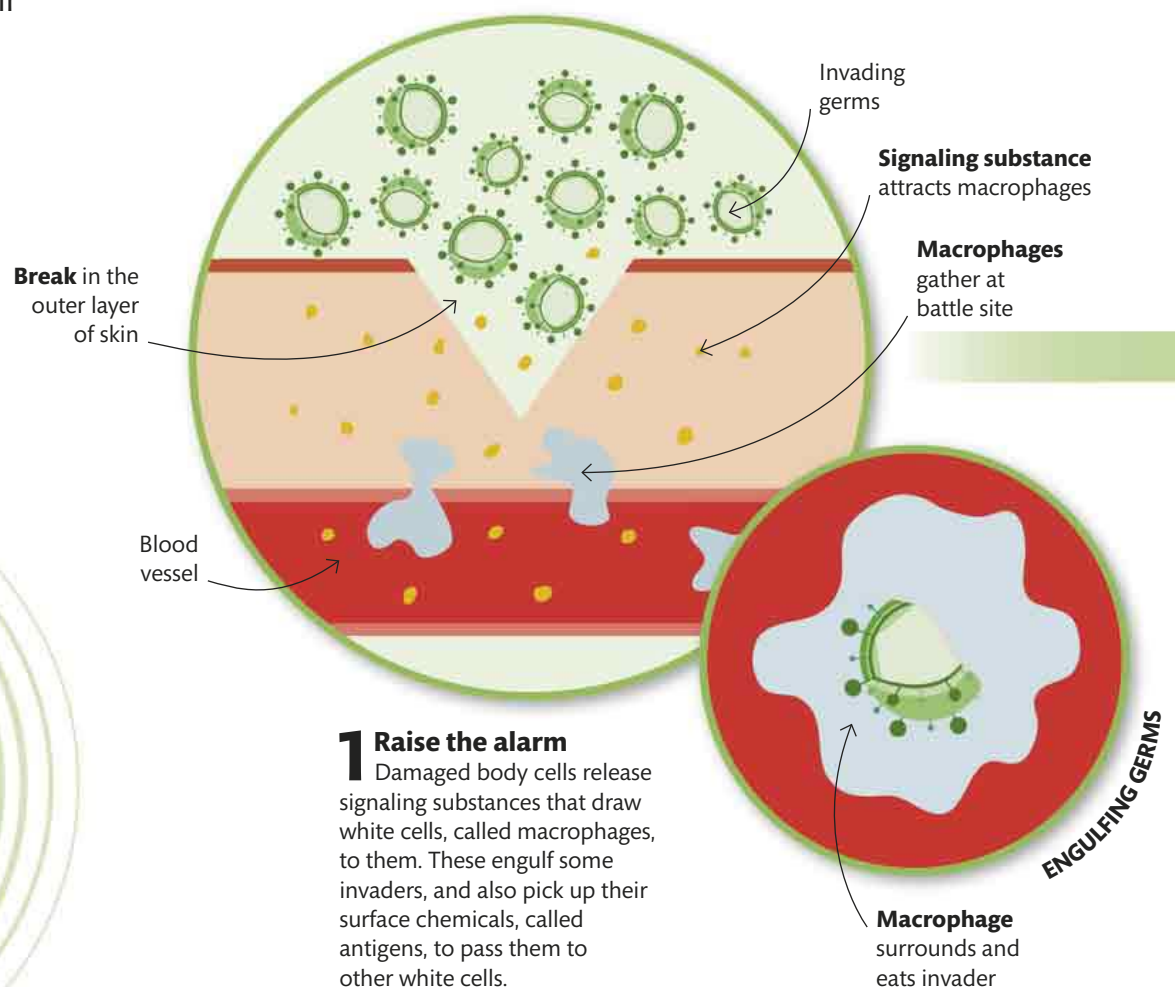
Any break in the protective outer layer of dead skin allows germs to get into tissues. Once inside, they damage cells, take nutrients from them, and multiply. If they enter the skin's blood vessels, they can spread around the body in minutes. So white cell defenses must gather fast at the war zone, ready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

“All the white blood cells together weigh twice as much as the brain”



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.





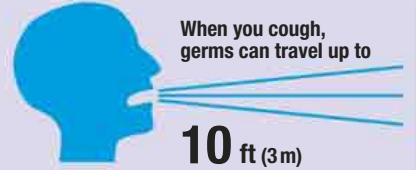
ALLERGIES

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



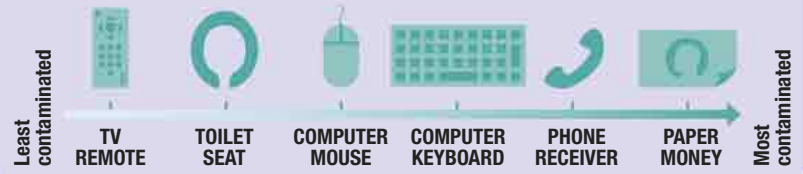
10 million bacteria can typically be found on one hand



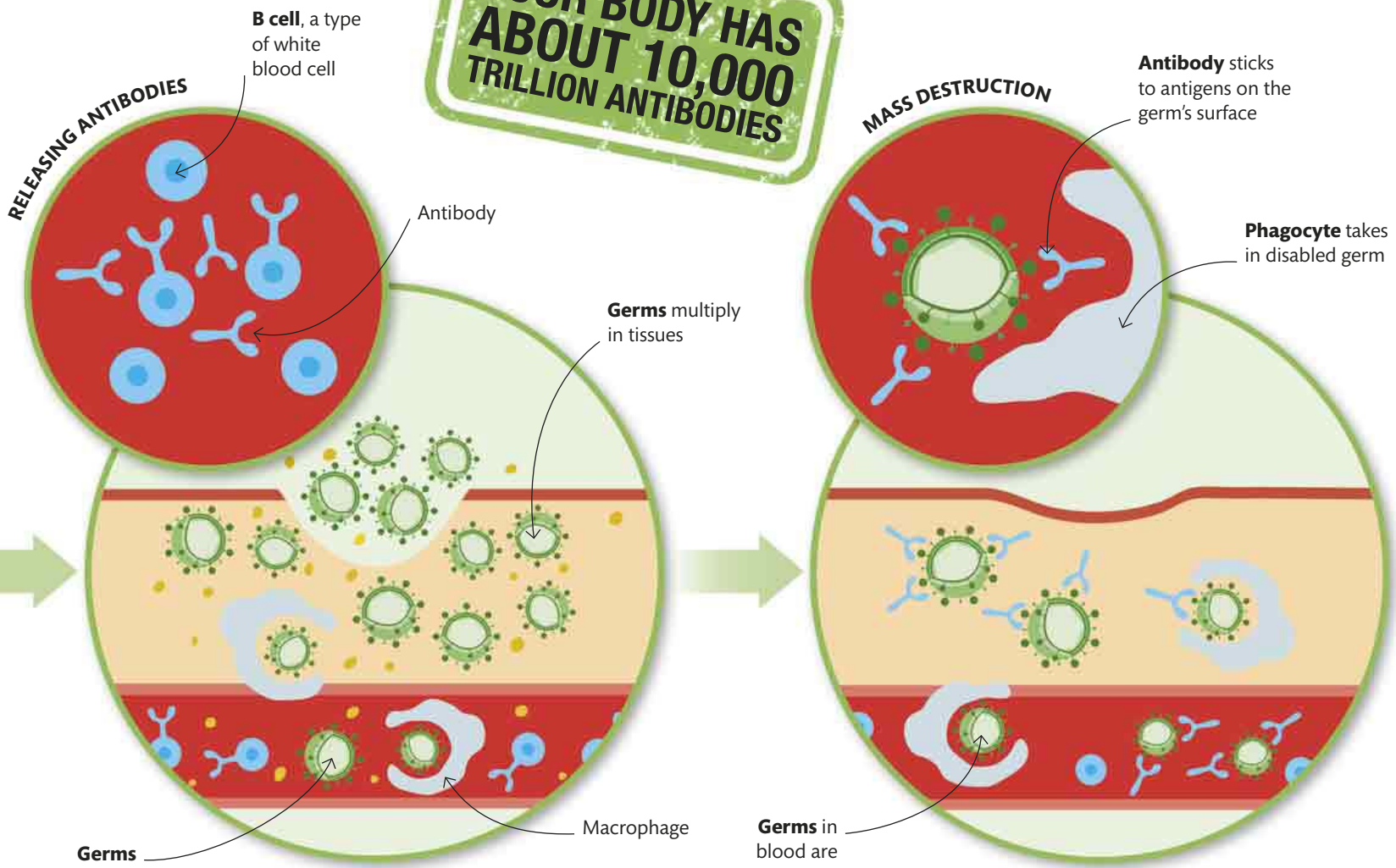
When you cough, germs can travel up to

10 ft (3m)

CONTAMINATION SCALE



YOUR BODY HAS ABOUT 10,000 TRILLION ANTIBODIES



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 microgaps 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.

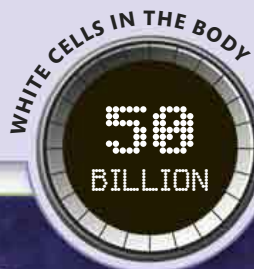
STATS AND FACTS

LIFESPAN OF MACROPHAGES



NUMBER OF MACROPHAGES

 **2,000** Total macrophages that would fit on a 1 mm period



**“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.



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: lumps called blebs form on the surface (shown above), drop off, and are cleared away by scavenging white blood cells until the entire cell is gone. This process is called apoptosis. It prevents the buildup of old, weak, damaged cells that would otherwise clog blood vessels, leak wastes, and cause other problems.

“Human skin is completely regenerated every four weeks”

Fat cells are replaced every 10 years

Cartilage at end of bone protects it



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.





Scalp hairs
last 3-6 years

Dendrites make
new links to
other neurons

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.

Red blood cell
in open wound

Platelets
in blood
rush to the
wound

Scab forms on the
surface of the skin

**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 fibers, 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.

Fibrin threads
help form
a mesh

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.

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.

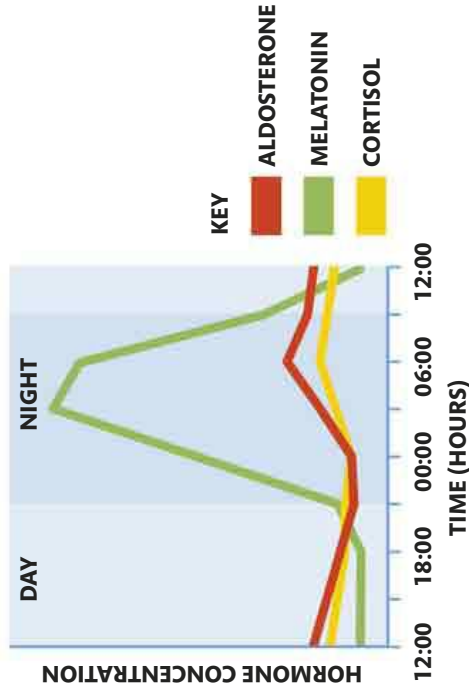
Hypothalamus
links the nervous and hormonal systems

Pituitary gland
produces hormones that control other hormone glands

Thyroid gland
controls metabolism, protein production, and body temperature

Parathyroid gland
controls calcium and phosphate mineral levels, vital for healthy bones

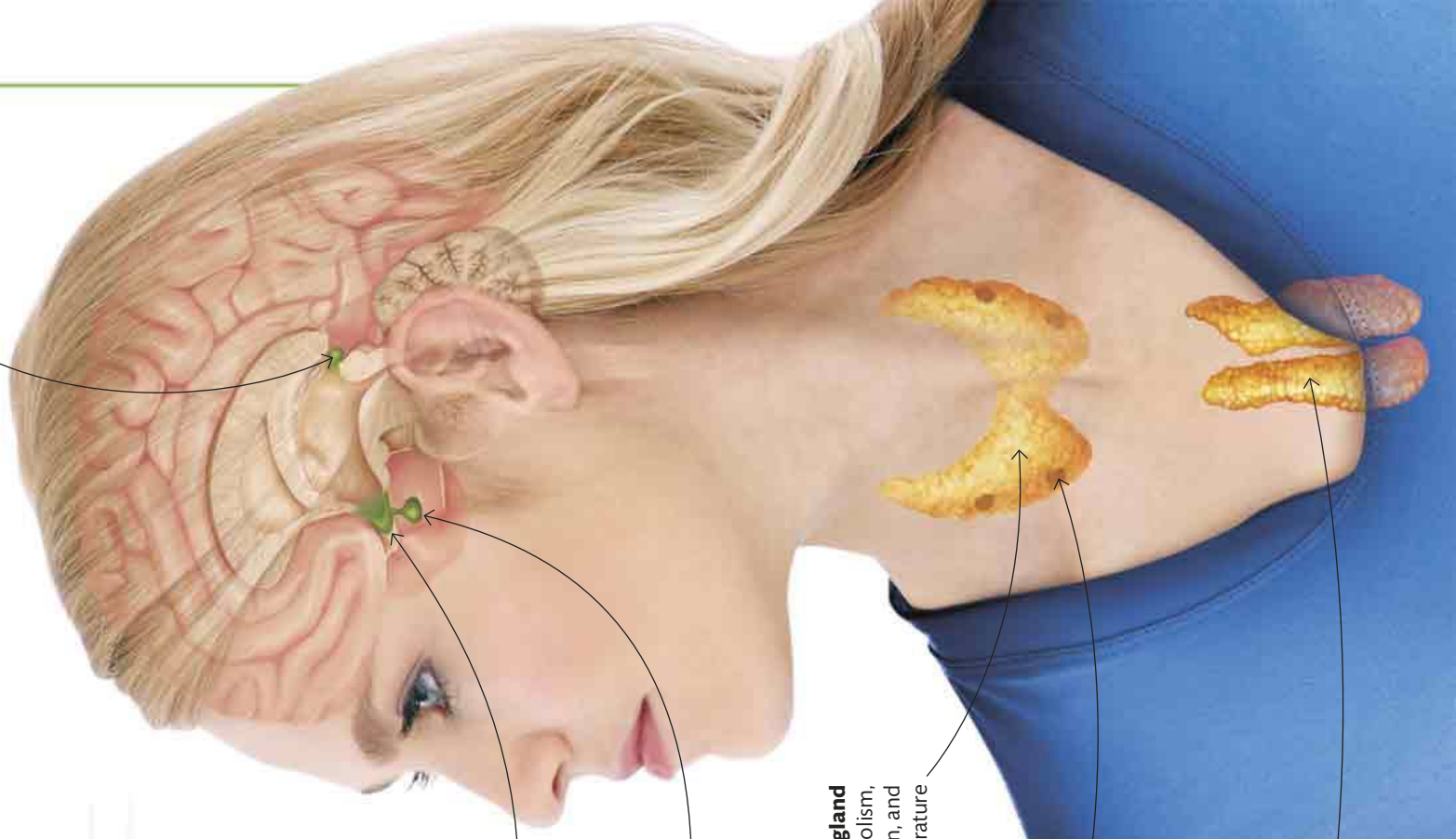
Thymus gland
stimulates the development of white blood cells and the growth of the body



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.

Pineal gland
makes melatonin, which affects sleep and wakefulness



“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.

Adrenal gland
produces hormones that control water levels and respond to stress

Liver
influences blood vessels, fluid levels, and cell growth

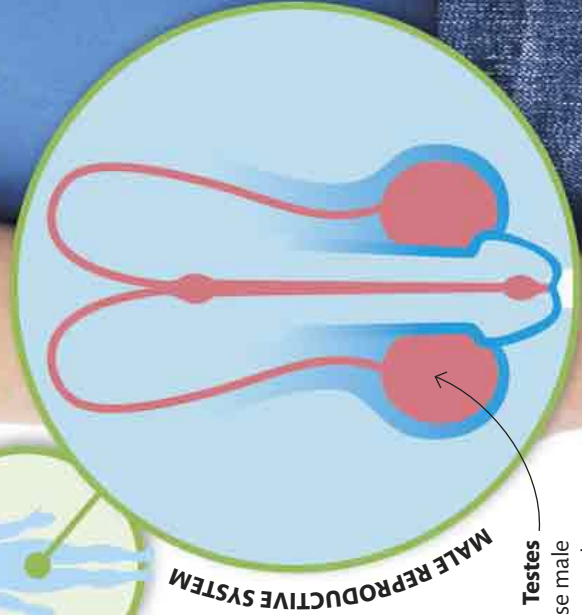
Kidney
influences red blood cell production

Pancreas
produces insulin and glucagon to control blood sugar

Stomach
produces gastrin and other hormones involved in digestion

Ovary
produces female hormones, such as estrogen

Testes
release male hormones, such as testosterone



DANGER, DANGER!

Stress hormones

From concerns 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. Epinephrine also affects blood glucose levels and prepares the body to face danger—the “fight or flight” reaction.

“Epinephrine makes you perceive things fast as normal”

Caffeine leads to adrenaline release



STRESS AND THE BRAIN

Epinephrine’s relative, norepinephrine, is also made in the adrenal glands and has similar effects. 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.

Urine

Reduced blood flow through kidneys slows down urine production (see pp. 154–55).



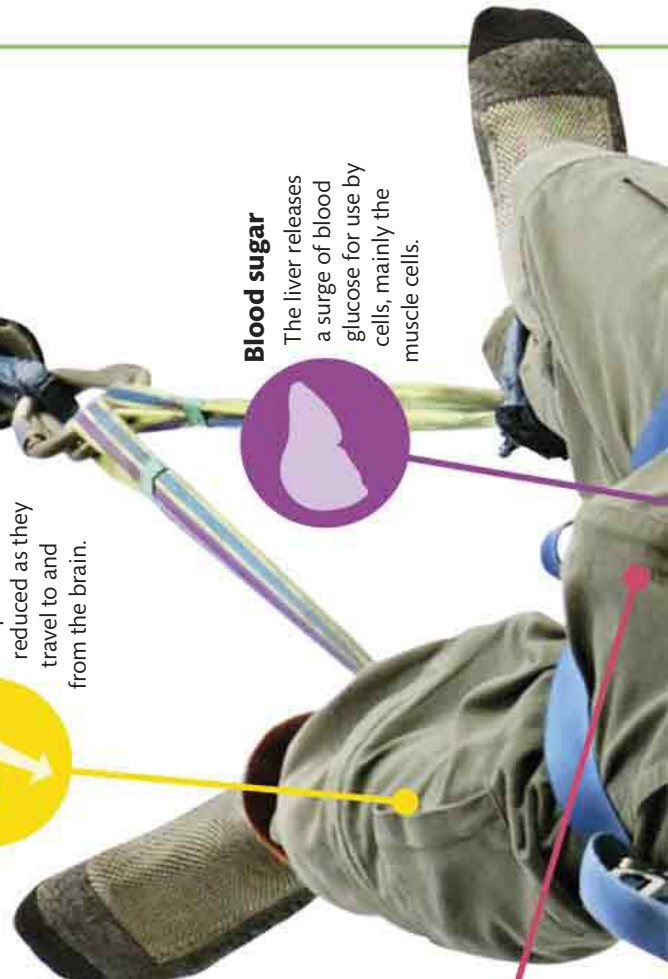
Pain

Nerve signals for pain are reduced as they travel to and from the brain.



Blood sugar

The liver releases a surge of blood glucose for use by cells, mainly the muscle cells.





Sweat
The skin sweats to cool the body when muscles are active.



Digestion
Blood flow to the stomach and intestines reduces, giving the fluttery feeling of butterflies in your tummy.



Breathing
Airways widen and the lungs expand faster and deeper, to get more oxygen.



Muscles
Extra blood flow, carrying oxygen and glucose, allows muscles to put in extra effort.



Mouth
Saliva production and release slow or even stop, producing a dry mouth.



Eyes
The pupils widen and the brain concentrates on what they see.



Brain
Blood flow to the brain increases so that all its parts can work at top speed.

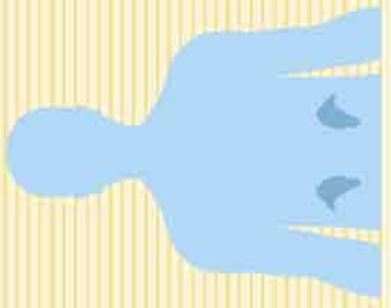


Hearing
There is no direct effect on the ears, but the brain's hearing centers become extra-alert.



Heart
The heart pumps faster and with more force, increasing blood flow and pressure, so more blood goes where it is needed.

AT A GLANCE



- **LOCATION** Adrenal glands sit on top of kidneys
- **SIZE** Height $\frac{3}{4}$ in (2 cm); length 3 in (8 cm); weight $\frac{3}{16}$ oz (5 g)
- **FUNCTION** The adrenal glands produce hormones, including the stress hormones, cortisol, epinephrine, and norepinephrine, as well as those affecting urine production.

EPINEPHRINE KICK

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

“Epinephrine levels are the 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

329 mph
(530 km/h)



STREAMLINE
HEAD-DOWN

186 mph
(300 km/h)



STANDARD
HEAD-DOWN

124 mph
(200 km/h)



STANDARD
BELLY-DOWN

FORMATION SKYDIVE



400

people, largest
group freefall

AGE OF OLDEST SKYDIVER

101

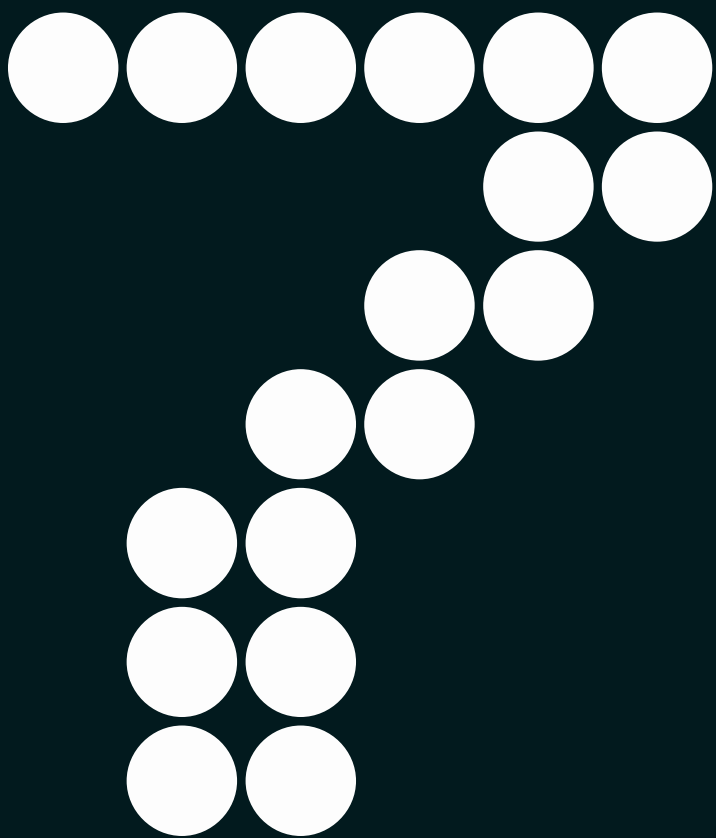




Daredevil diving

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 upward, before opening his parachute to glide safely back to Earth.

“The highest ever freefall was from 24 miles (39 km) above the ground”



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

The first week

Every amazing human body, with its billions of cells, begins as a single cell—a tiny speck smaller than this period. 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.

SPERM CAN SURVIVE UP TO 5 DAYS

Zona pellucida is a tough protective layer

1 Sperm reaches egg A sperm cell touches the outer layer of an egg cell.

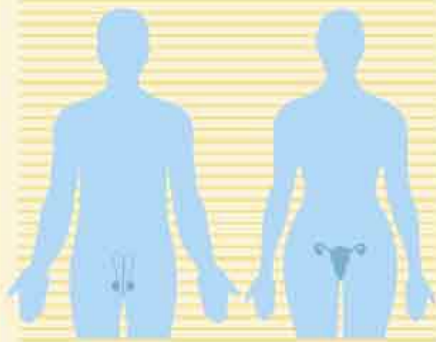
Male pronucleus, the male genetic material

2 Sperm enters egg The sperm cell dissolves and burrows through the outer layer. Only a single sperm will penetrate the egg.

3 Sperm head The sperm head leaves its outer covering behind and moves toward the pronucleus of the egg.

Female pronucleus, the female genetic material

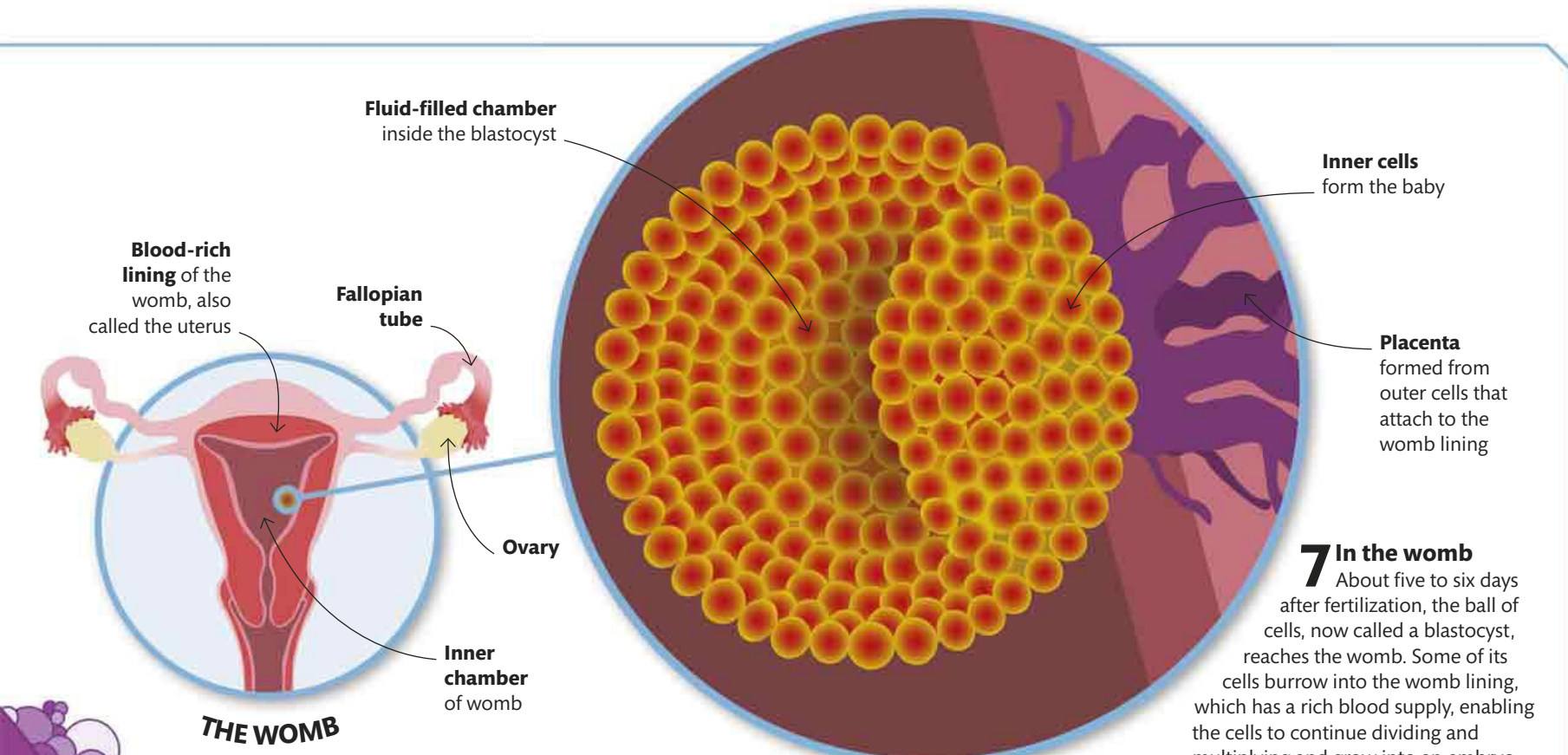
AT A GLANCE



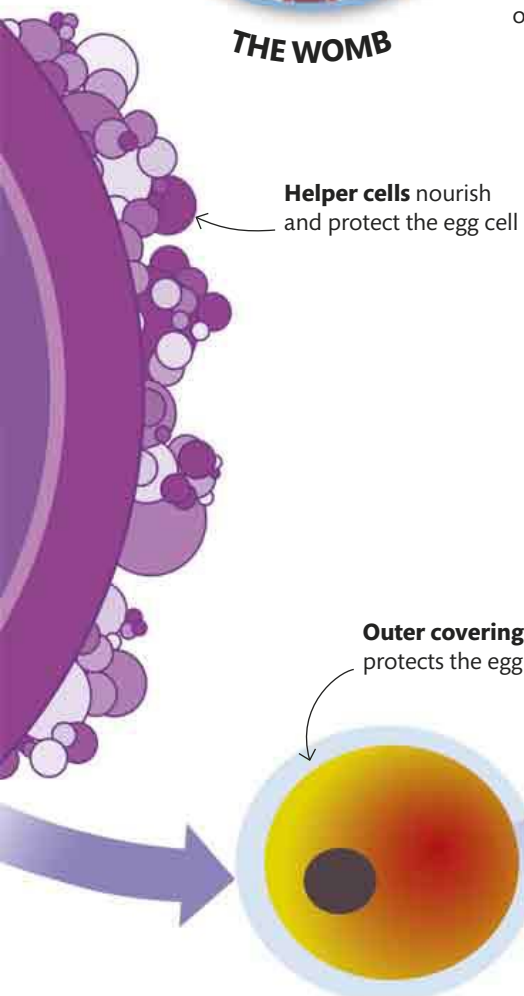
MALE

FEMALE

- **SIZE** Testes 2 in (5 cm) long; ovary 1½ in (4 cm) long, womb 3 in (8 cm) 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

	300,000 AT BIRTH
	10,000 AT 40 YEARS

EGG AND SPERM SIZE

	3,000 SPERM PRODUCED PER SECOND
	0.15 mm EGG CELL
	0.005 mm SPERM CELL HEAD

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.

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 18 in (46 cm), weight is 85 oz (2,400 g).

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

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 14 in (35 cm), weight is 23 oz (650 g).

Mother's blood vessels in placenta

LIFE SUPPORT SYSTEM

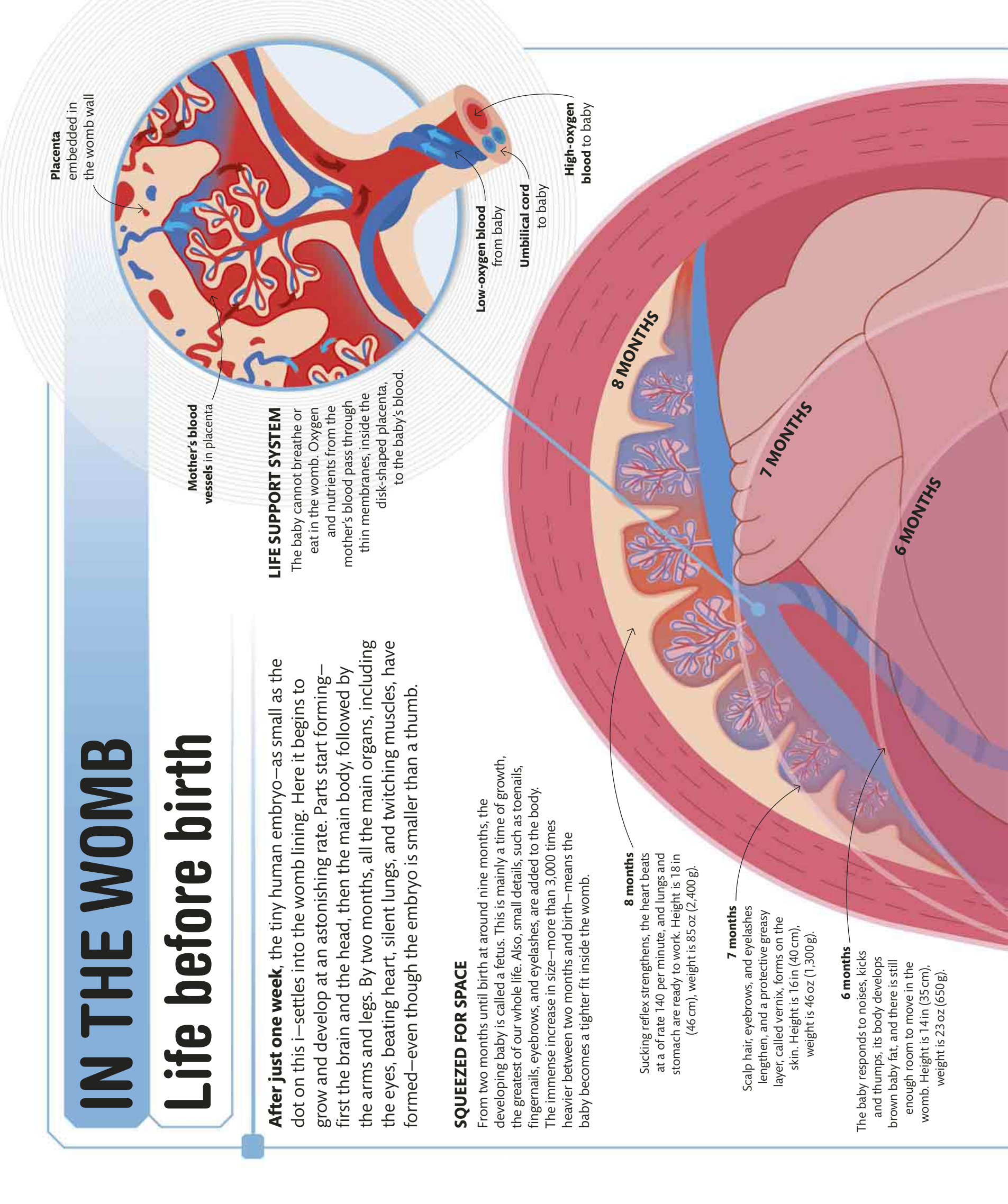
The baby cannot breathe or eat in the womb. Oxygen and nutrients from the mother's blood pass through thin membranes, inside the disk-shaped placenta, to the baby's blood.

Low-oxygen blood from baby

Umbilical cord to baby

High-oxygen blood to baby

Placenta embedded in the womb wall



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

5 MONTHS

4 MONTHS

3 MONTHS



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 that the baby is developing normally.

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

Umbilical cord
 connects the baby to the mother's placenta

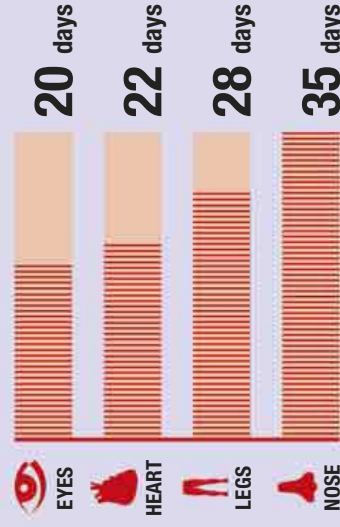
3 months
 The heart is beating, the muscles make early movements, and even the kidneys are working. Length of the fetus is 2½ in (6 cm), and weight is 0.5 oz (15 g).

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

Womb's muscular wall

STATS AND FACTS

TIMELINE OF DEVELOPING UNBORN CHILD



21 weeks

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

ADDED AT MOST RAPID GROWTH

5,000
 CELLS PER SEC

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. Nonidentical twins happen when two separate fertilized eggs develop into babies. For nonidentical triplets, there are three fertilized eggs, and so on.

STATS AND FACTS

CHANCES OF MULTIPLE BIRTHS



Single birth

PREGNANCY PERIOD

40 WEEKS
NORMAL BIRTH 

36 WEEKS
TWIN BIRTH 





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

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.

THE FIRST TEN YEARS

Each baby is an individual and develops at her or his 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.

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



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



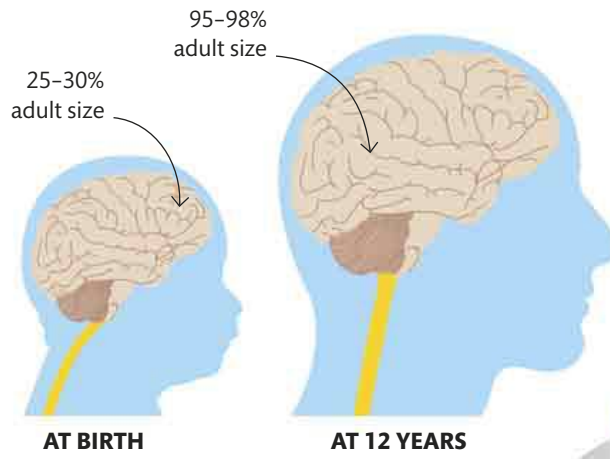
2-3 YEARS

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 percent of adult size, but has all the neurons it needs. It shoots up in size to 80 percent 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.



Bouncing a ball off one knee shows leg-eye coordination

Dressing and undressing self without help

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

3-6 YEARS

"Self-centered" 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 sports, 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

Children need 10-12 hours of sleep to grow

TEEN TIME

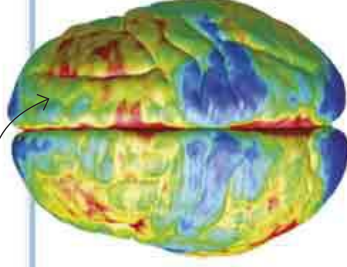
Reaching puberty

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.

Teenagers have more gray matter (red to green areas)

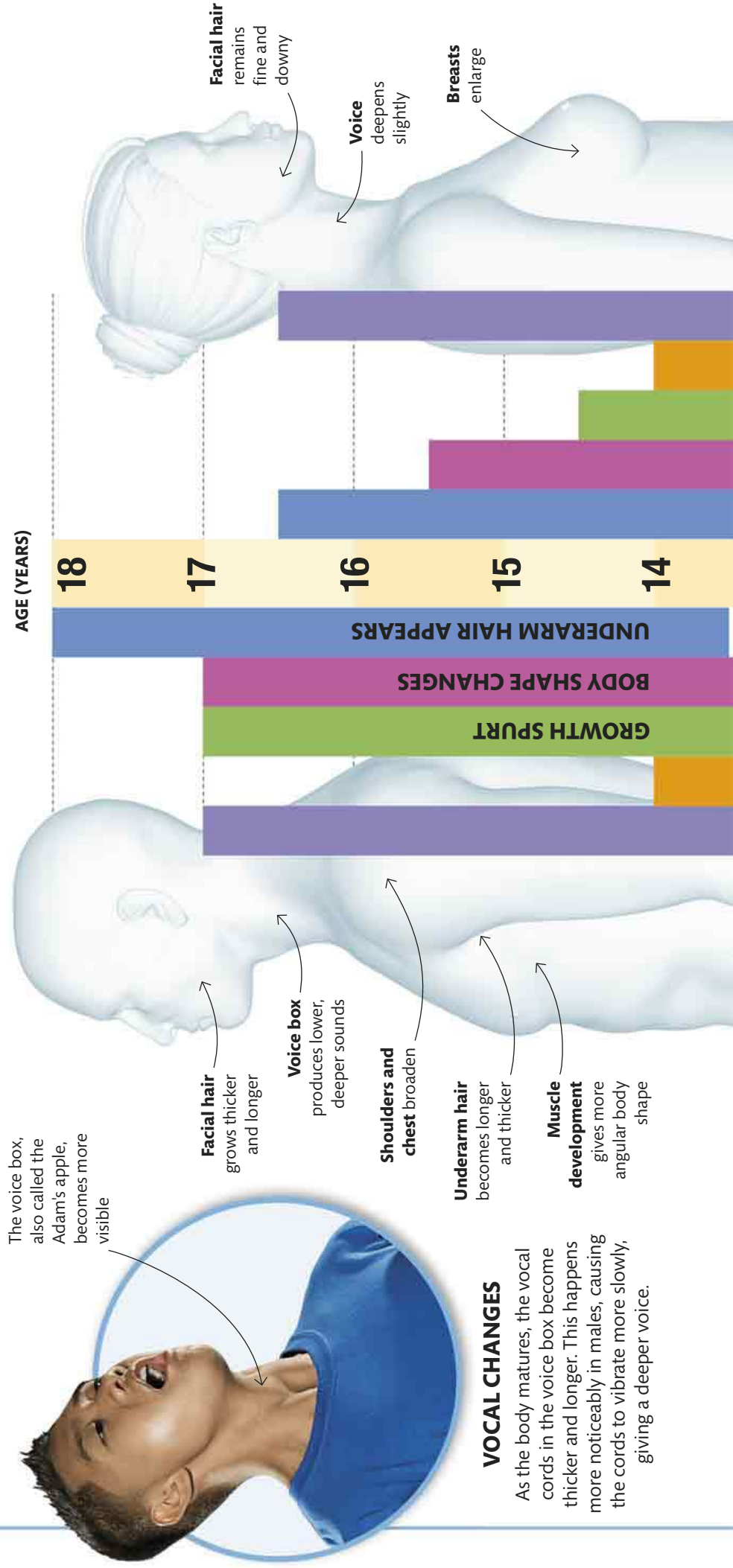


TEEN BRAIN

Adults have less gray matter after the rewiring process (shown in blue)



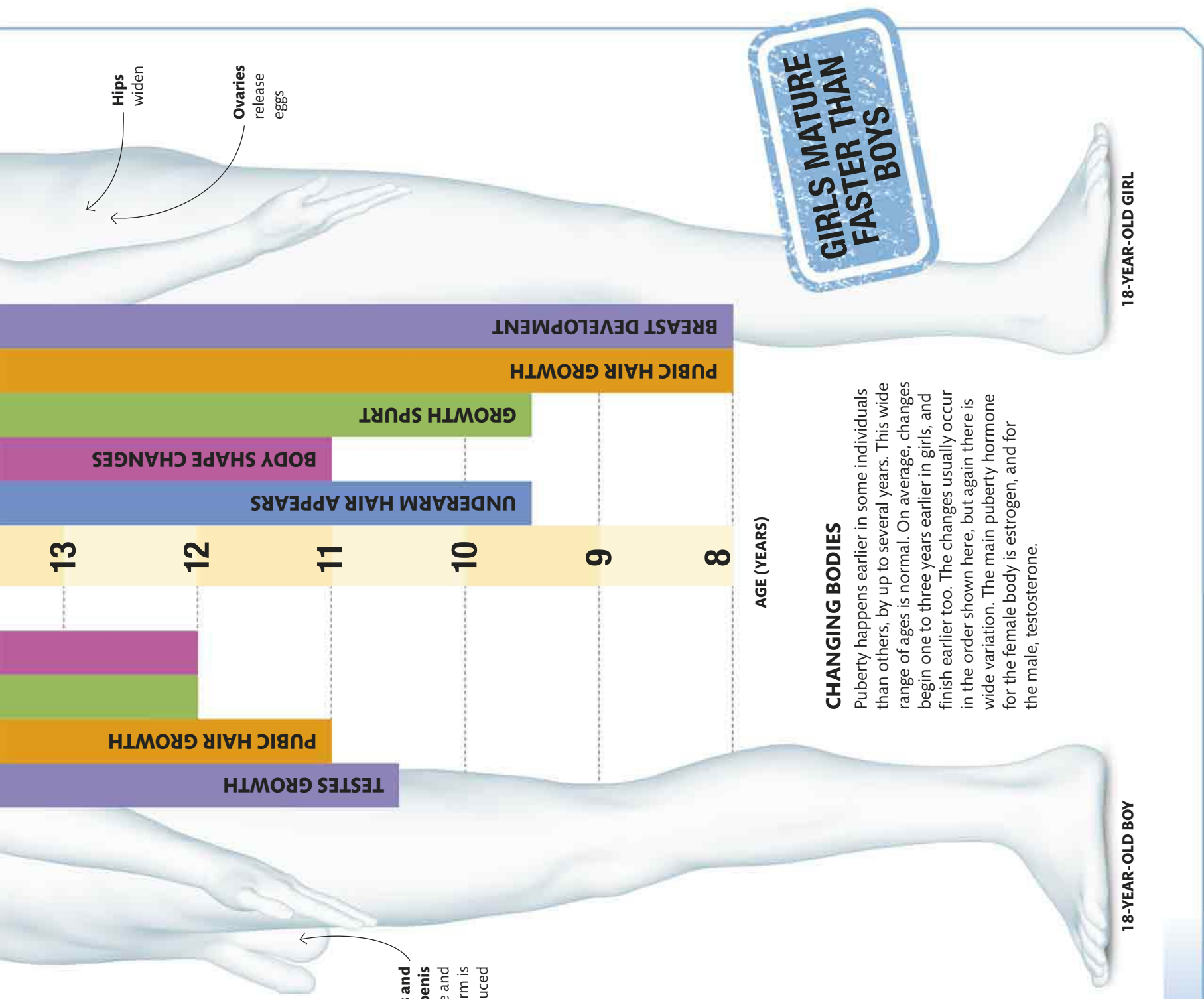
ADULT BRAIN



“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.



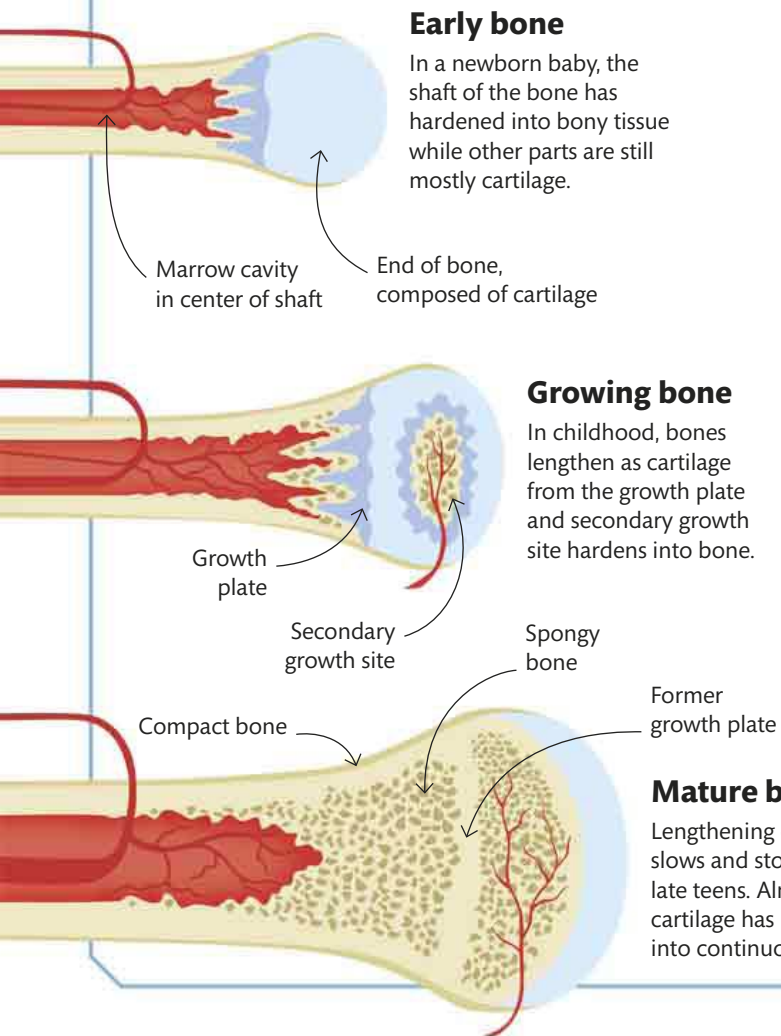
PHYSICAL PROGRESS

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.

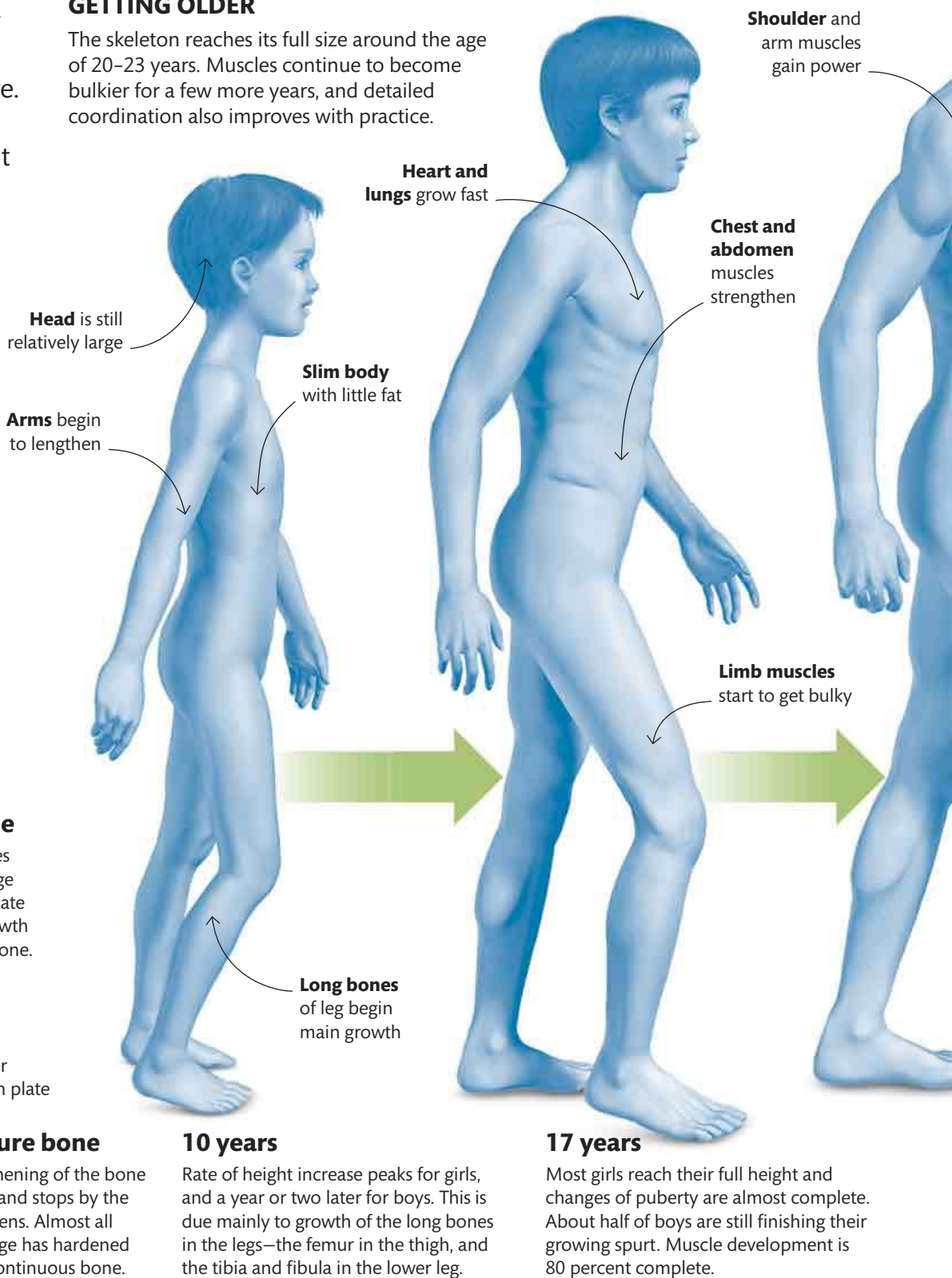
BONE GROWTH

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.



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.

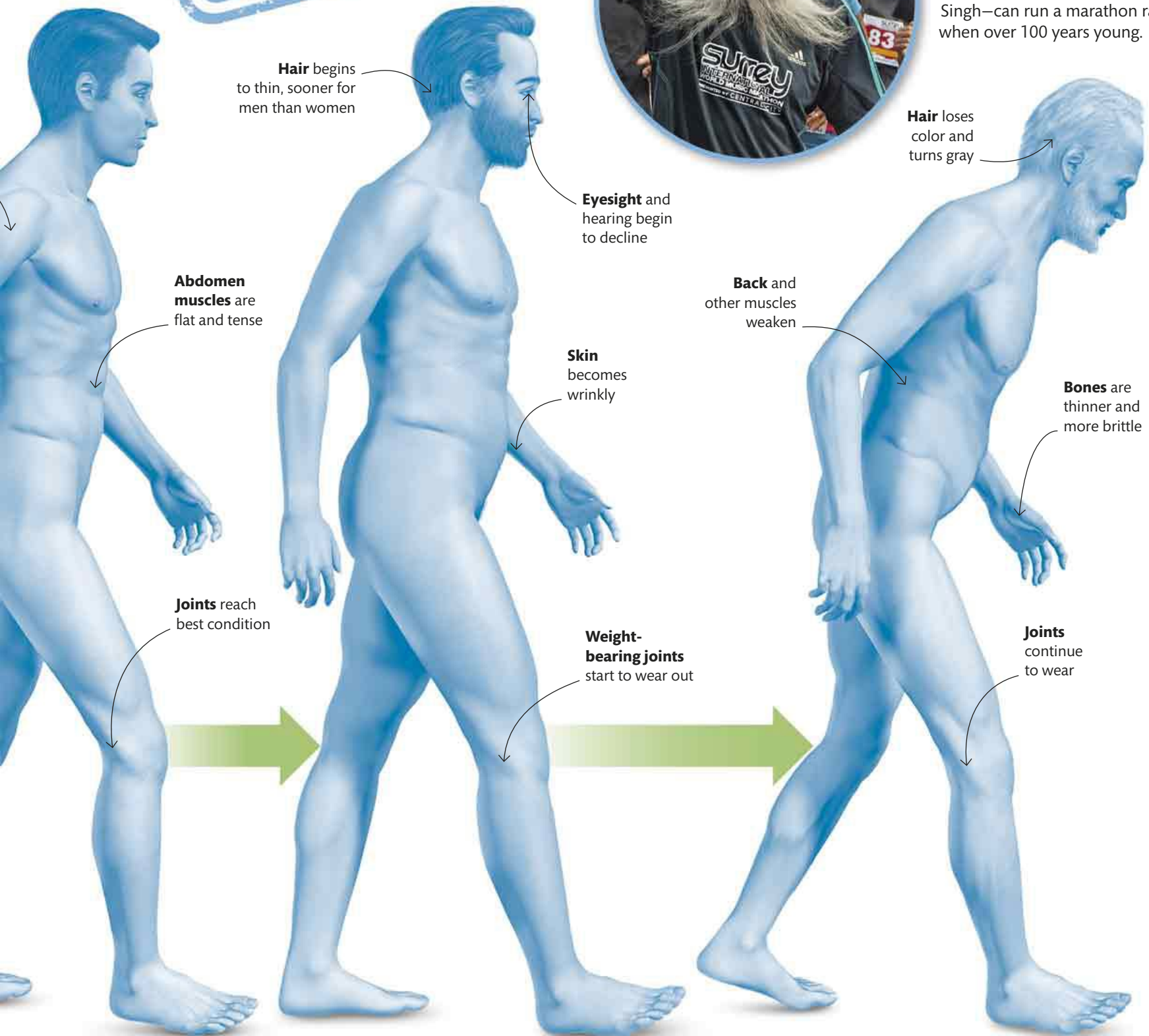


ALL MUSCLE FIBERS ARE PRESENT FROM BIRTH



KEEP ON RUNNING

As with the entire life cycle, the rate of aging 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.



Hair begins to thin, sooner for men than women

Eyesight and hearing begin to decline

Hair loses color and turns gray

Abdomen muscles are flat and tense

Back and other muscles weaken

Skin becomes wrinkly

Bones are thinner and more brittle

Joints reach best condition

Weight-bearing joints start to wear out

Joints continue to wear

25 years

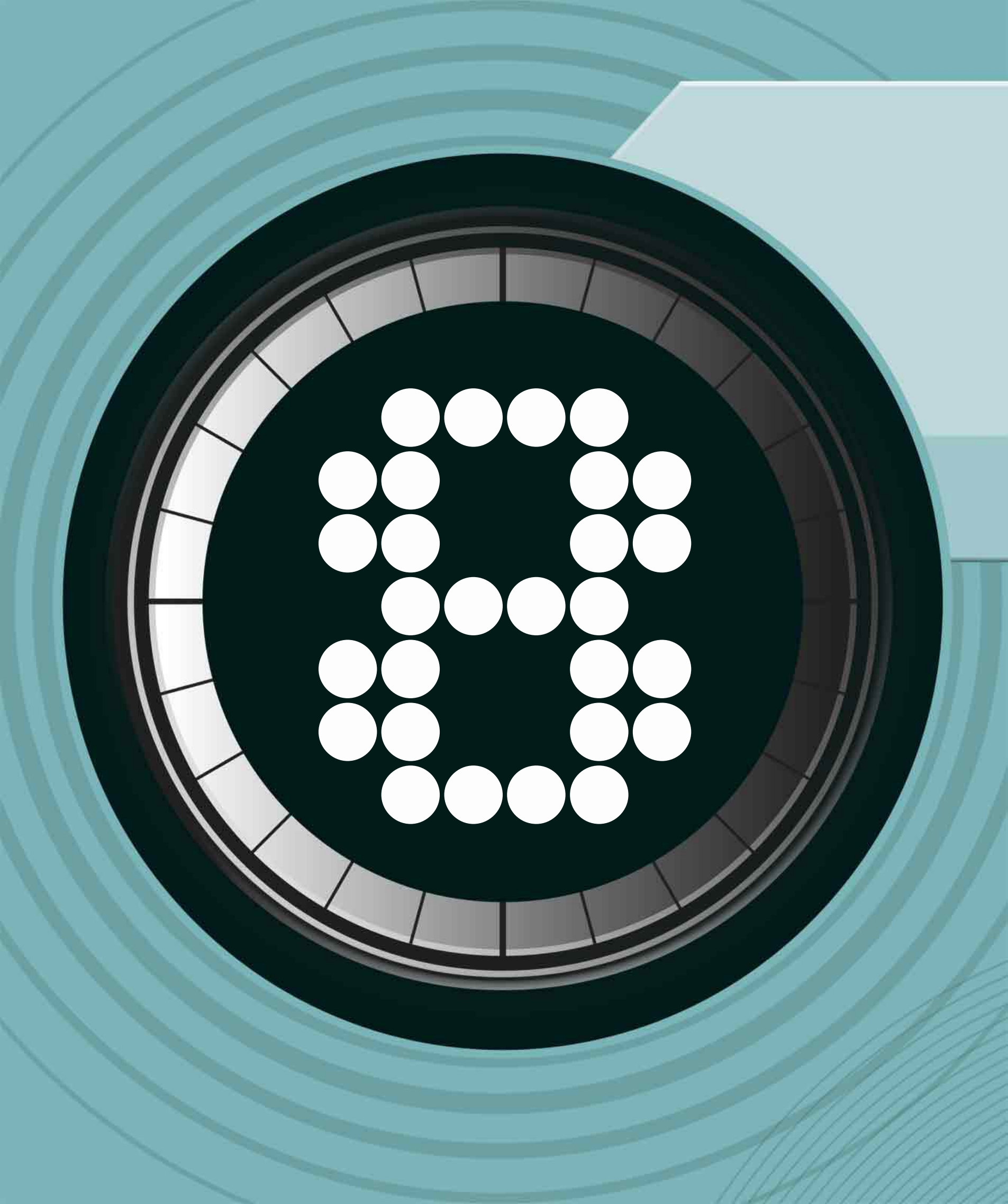
The average body is at its greatest height and maximum upright posture. Muscles are ready for their fullest development, although this depends largely on the amount of physical exercise and training.

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 sharp and reactions slower.

80 years

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



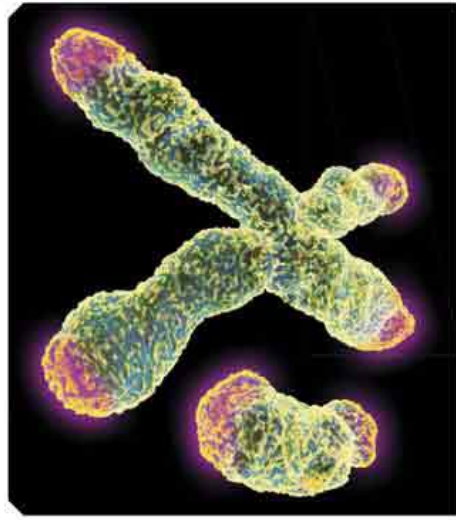
FUTURE HUMANS

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

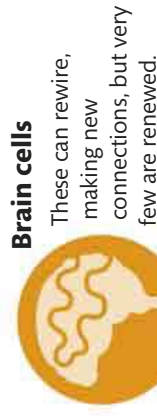
Do you ever imagine what it will be like to be old? In the future, the difference between old and young could disappear. Scientists are slowly starting to discover what causes living things to age and die. They can already make worms, flies, and mice live longer, so what about humans? One day it might 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.

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



Brain cells

These can rewire, making new connections, but very few are renewed.



Eyelashes

These fall out regularly and are replaced every 2 months.



Lens cells

These cells in the eye last well into old age.



Taste bud cells

These wear out quickly—most last no more than 10 days.



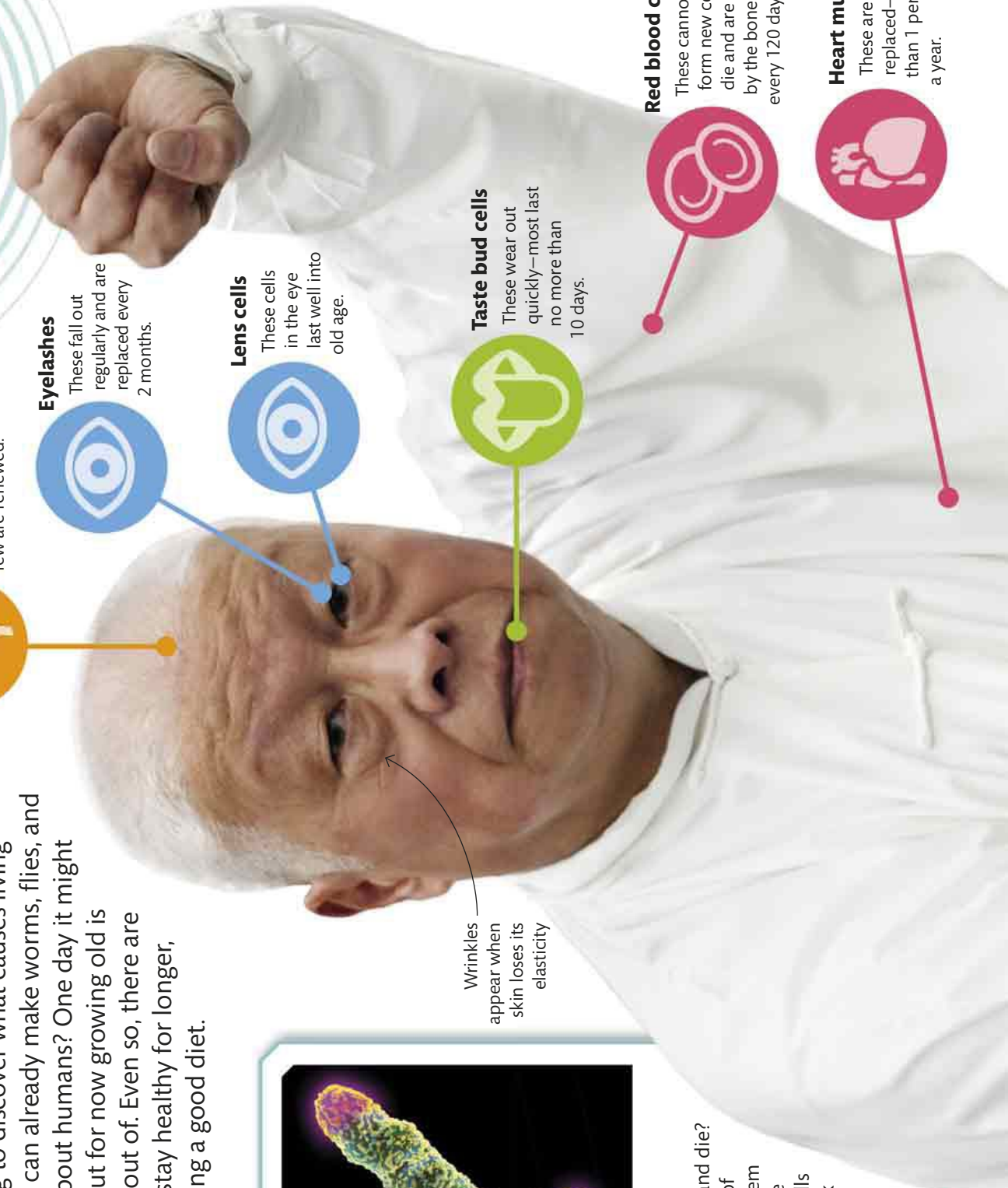
Red blood cells

These cannot divide to form new cells so they die and are replaced by the bone marrow every 120 days.



Heart muscle cells

These are rarely replaced—less than 1 percent a year.



Wrinkles appear when skin loses its elasticity

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 percent more elderly people in the world than there were in 2000.

Regular exercise can improve mobility and help fight off disease

Skeletal muscle cells
These last 15 years—much longer than smooth muscle cells, found in the blood vessels and bladder, which last only a few days.



Intestinal cells

Renew the entire gut several times throughout life.



Intestine lining

These cells are rubbed off by the passage of food and last only five days.



Skin cells

These are shed every day and renewed from below the surface every four weeks.

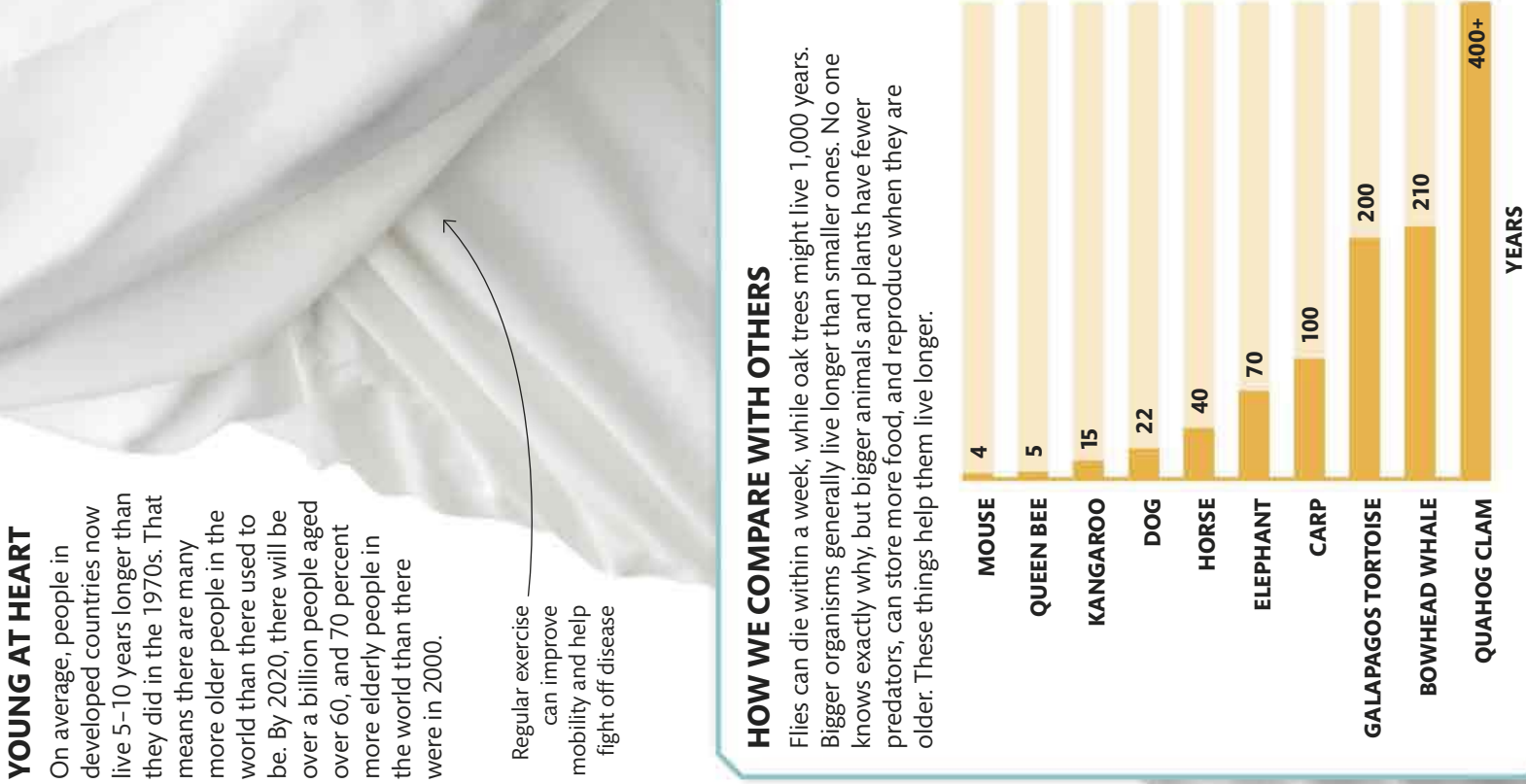


Bone cells

The entire skeleton is replaced every 10 years.



Joints suffer the most wear and tear, but can now be replaced



TO BOLDLY GO

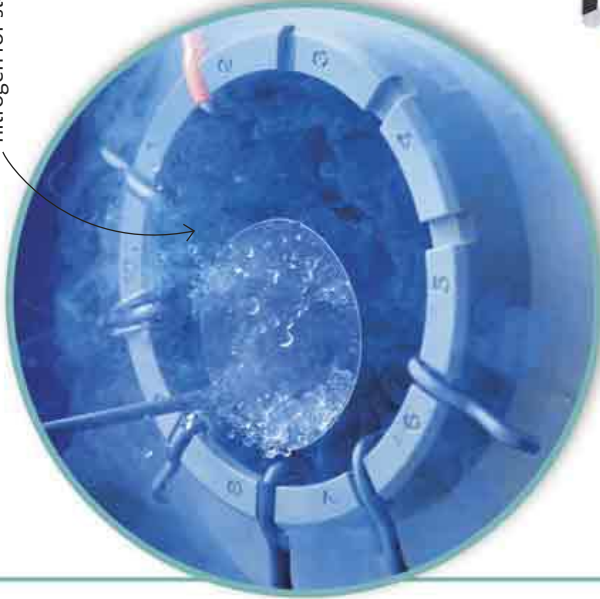
Life in space

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

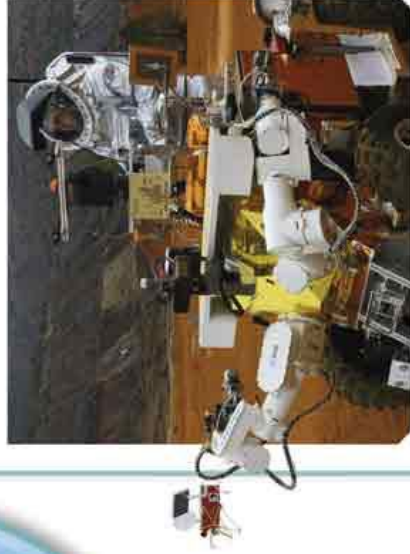
FEWER THAN 550 PEOPLE HAVE GONE TO SPACE

Eggs frozen in liquid nitrogen for storage



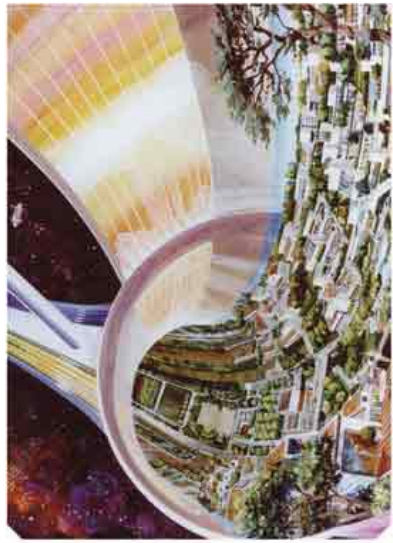
LIFE IN SPACE

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 uninhabitable 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.

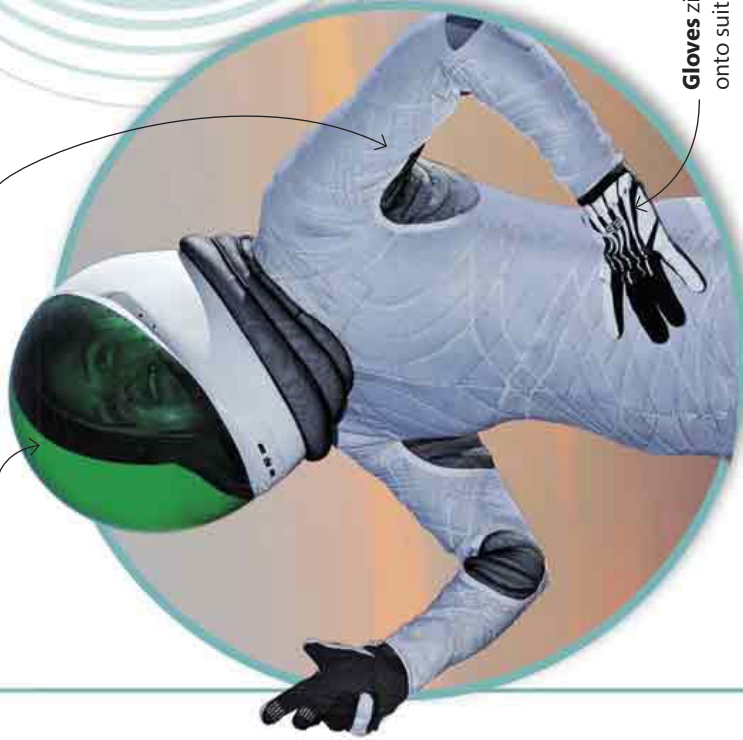


SPACE COLONIES

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

“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 from aging 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!

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.

SPARES AND REPAIRS

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 11 square feet (1 sq m) in these special culture dishes.



Artificially grown human skin being removed from a culture dish

Red blood cell in the bloodstream

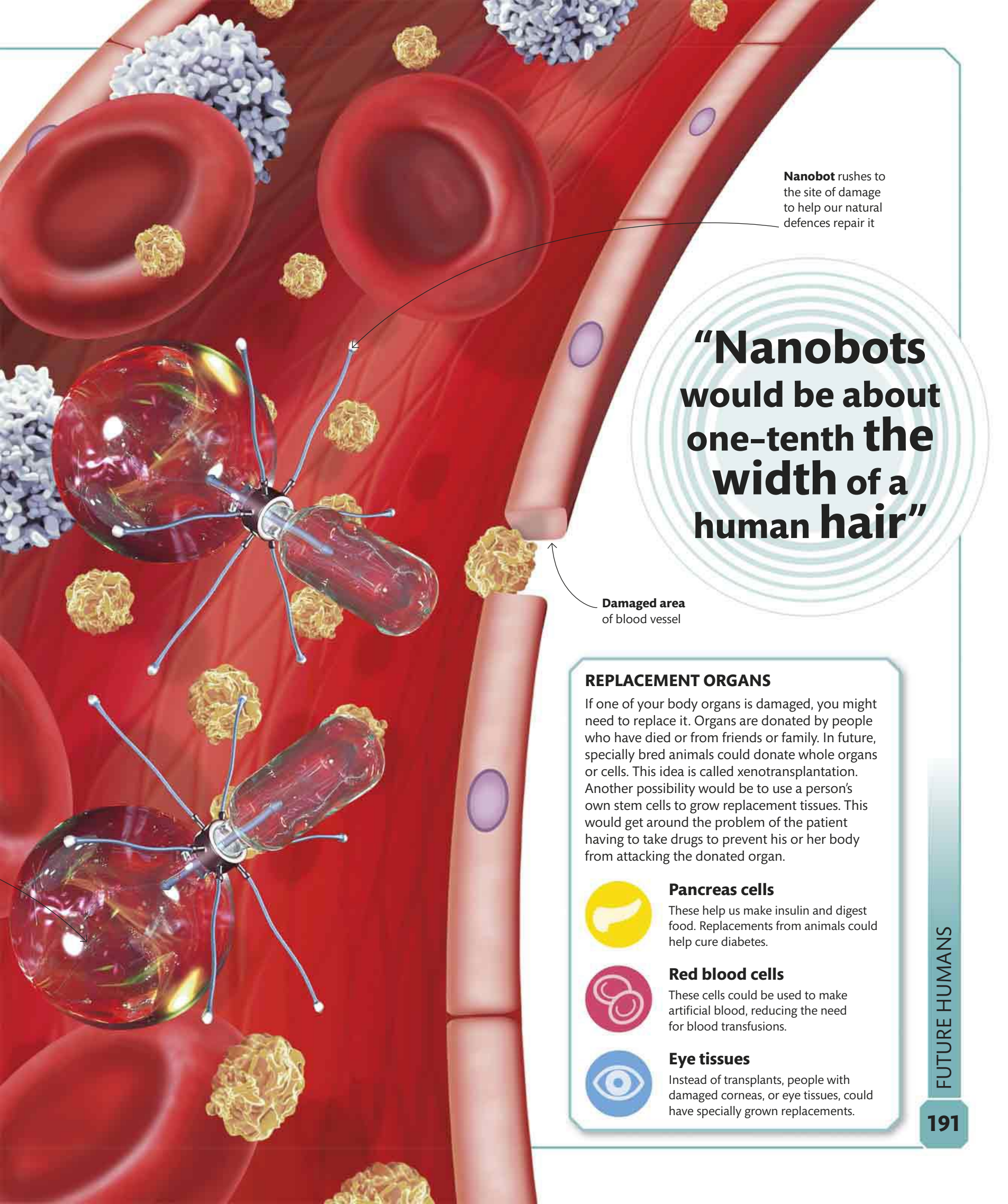
Gel contains nutrients needed by skin cells to grow

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.



Nanobot rushes to the site of damage to help our natural defences repair it

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

Damaged area of blood vessel

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 stay fit and active. Although our bodies constantly rebuild themselves, they wear out eventually. But as we slowly swap aging 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.

Bionic retina
uses a sensor chip to convert viewed images into electrical signals

Plug-in memory chip
could cure memory loss or give instant information

Visual processing chip
automatically identifies objects and sends information to the brain

Artificial nose
uses bionic sensors to detect and identify chemicals

Pacemaker with built-in battery corrects irregular heartbeats or heart failures

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.

Battery pack
powers exoskeleton

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.

Braces fitted onto legs enable forward motion

“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.

Battery-powered pacemaker



Carbon-fiber blades



Heart pacemaker

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

Strong plastic casing makes the prosthetic arm quicker and lighter to move

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?

ANIMAL CLONING HAS
**A 95–99%
FAILURE RATE**

DESIGNER BABIES

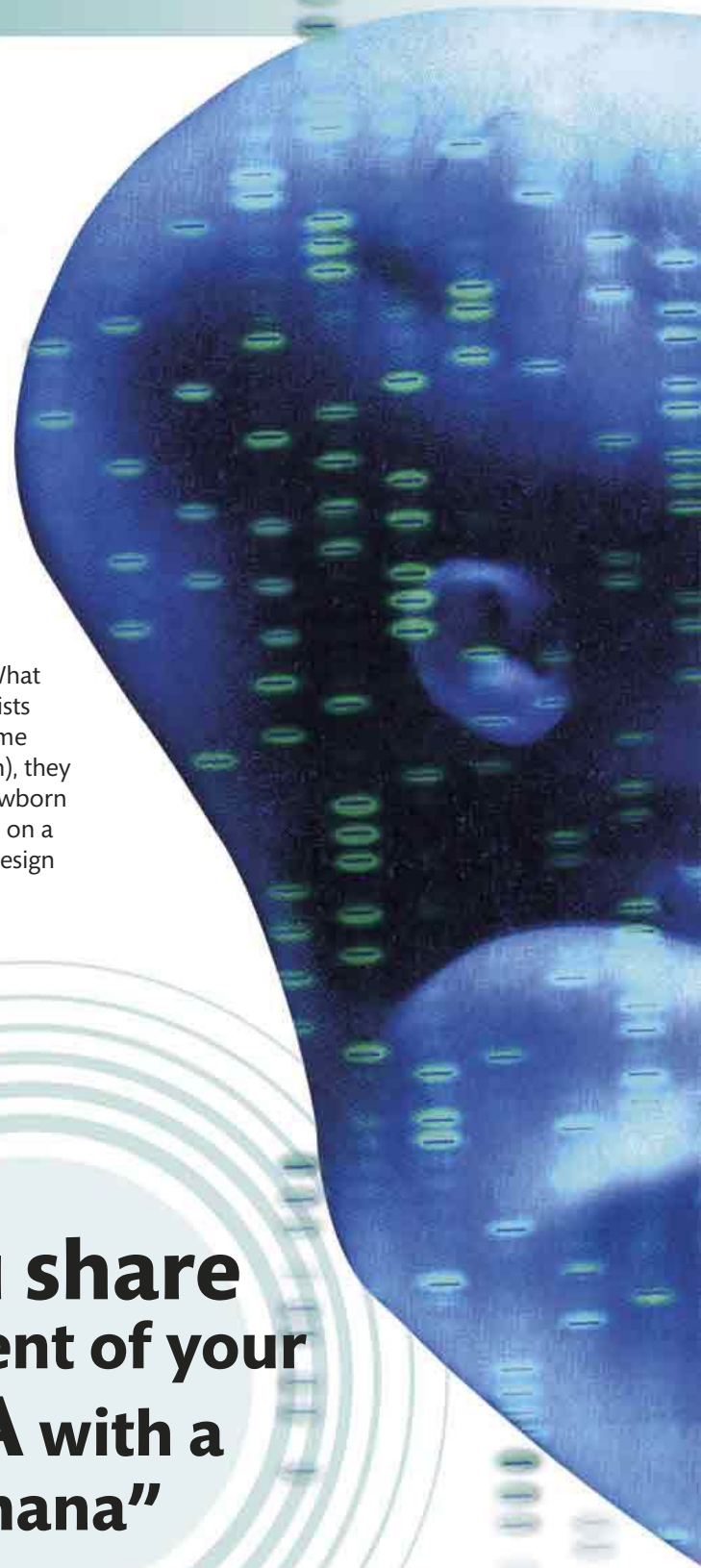
Should parents be able to choose their baby's sex before it's born? What about other features? Once scientists fully understand the human genome (our complete genetic information), they might engineer any aspect of a newborn child as easily as choosing options on a new car. Should humans dare to design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

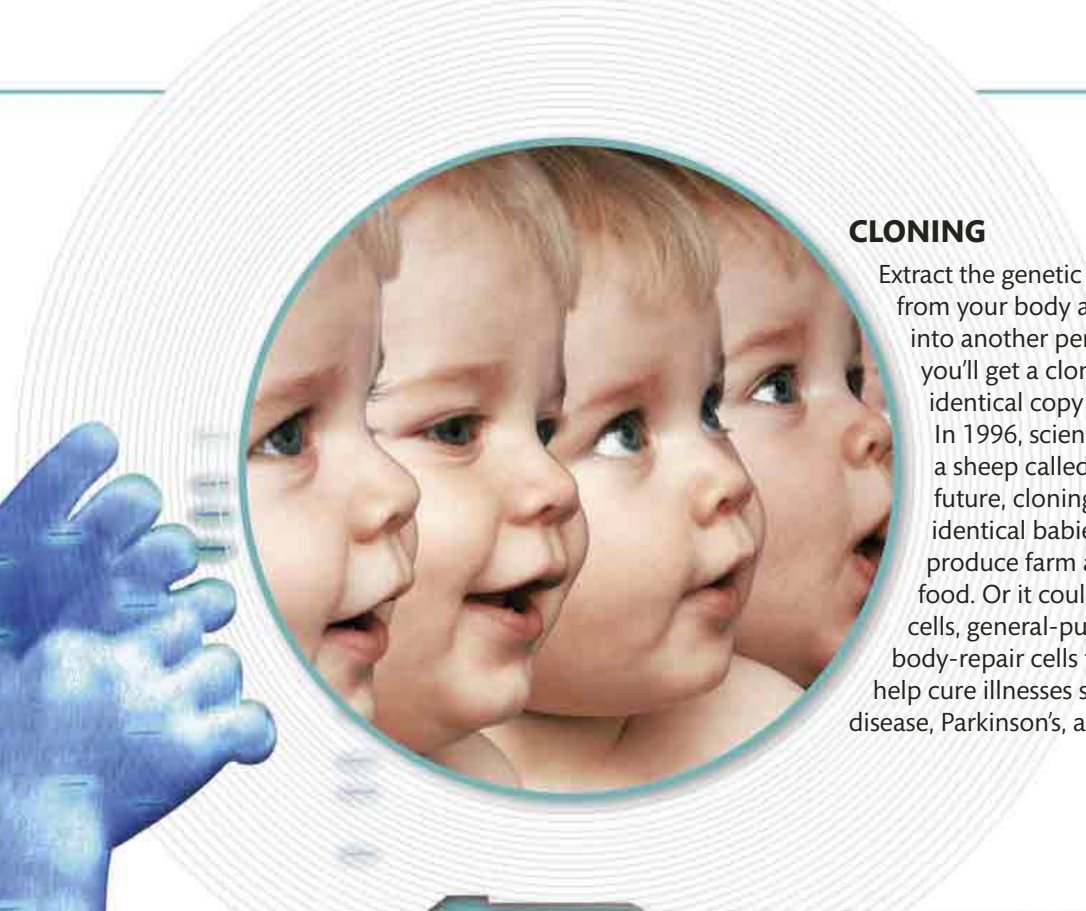


GENE THERAPY

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 percent 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, a bit like ordering a takeout meal. Doctors could give you a list of options from which you pick the ones you prefer. Many would think this unethical, but who knows how far we would go down the route of picking our "perfect child."



EYES

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



HAIR

Babies could be designed with a certain hair color, 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 amazing new opportunities. Could we blend computer technology with our brains to make ourselves much smarter?

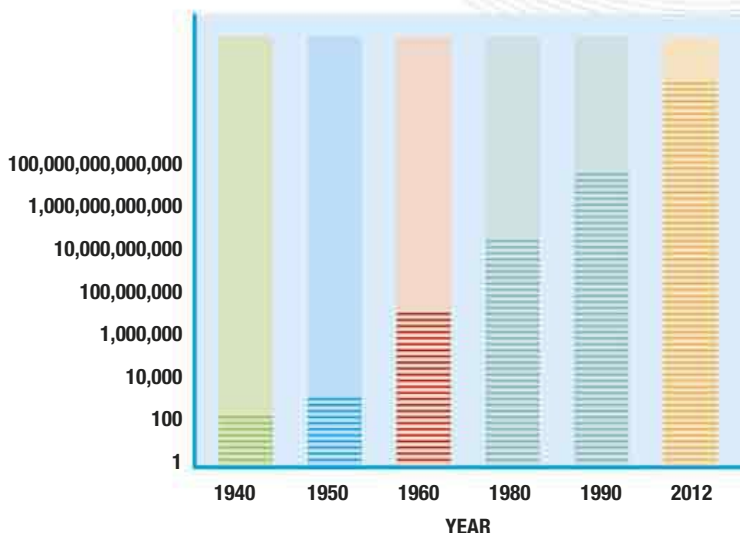
AUGMENTED REALITY

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 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.



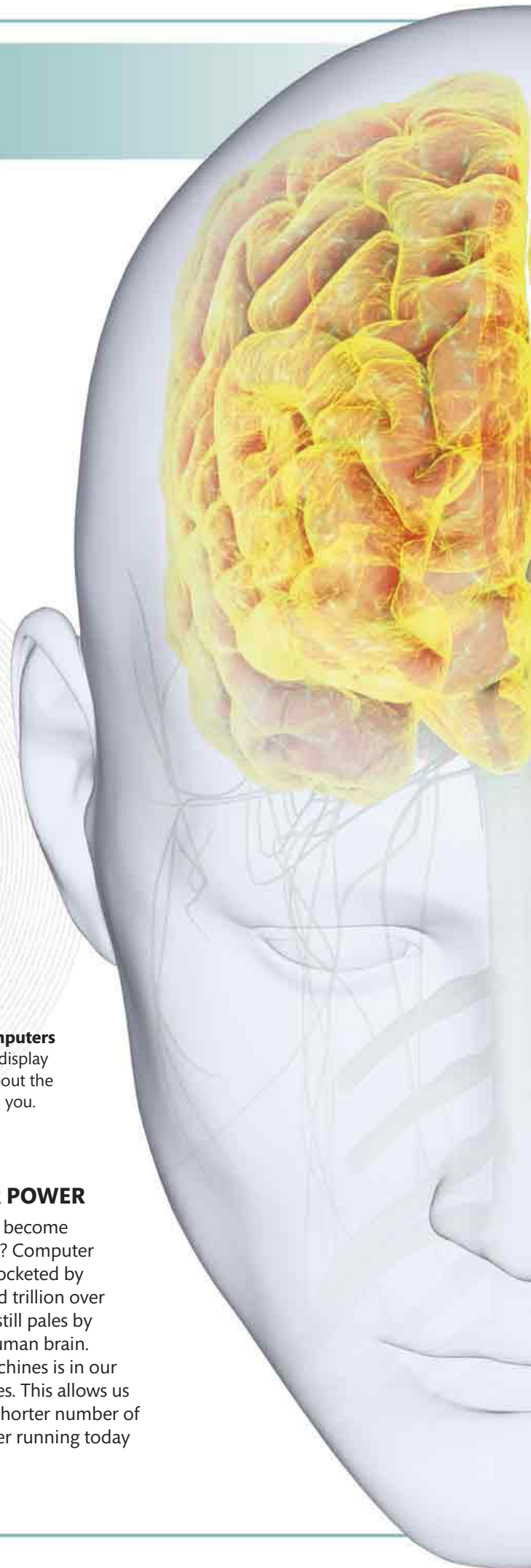
Wearable computers will be able to display information about the objects around you.

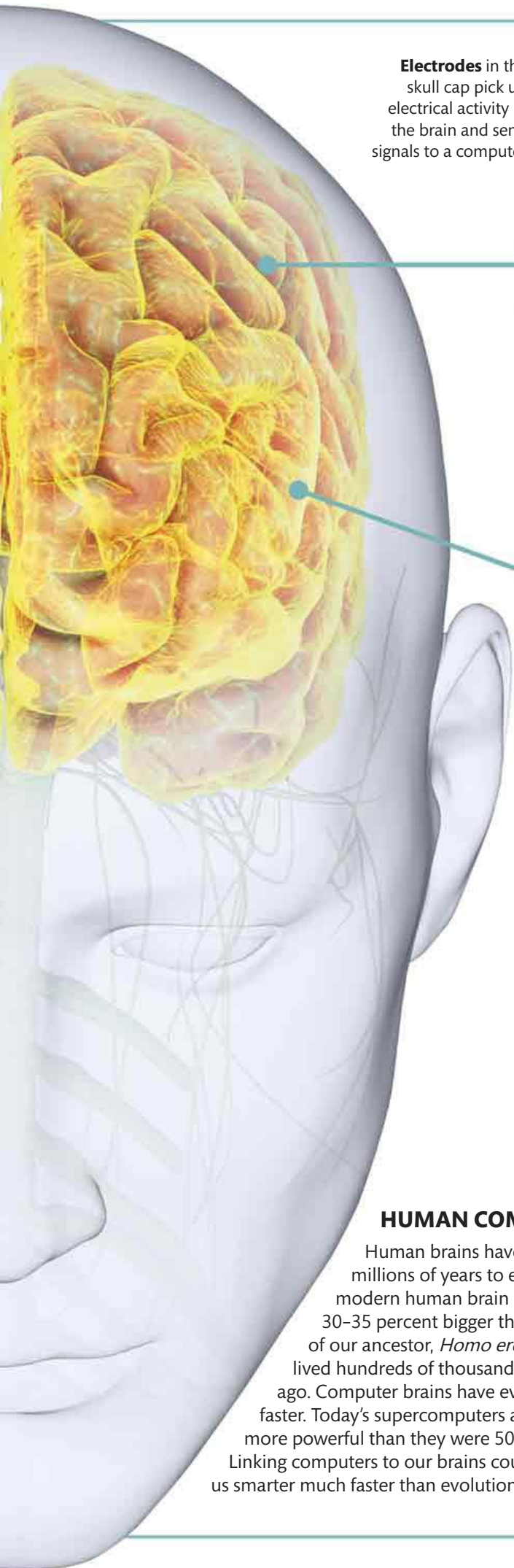
MEMORY (NUMBER OF OPERATIONS PER SECOND)



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 by comparison 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.





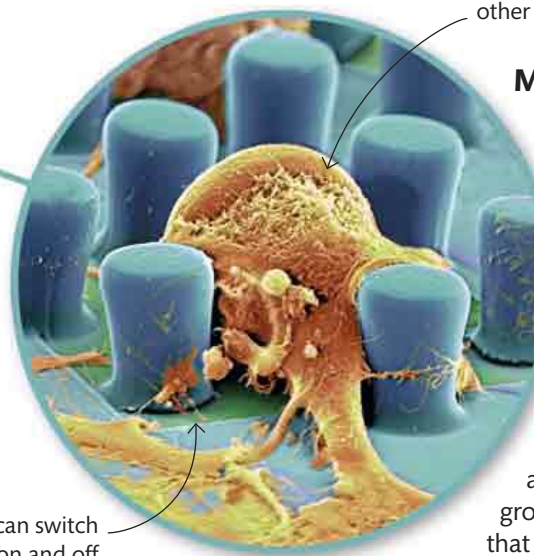
Electrodes in the skull cap pick up electrical activity in the brain and send signals to a computer



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 paralyzed people. They could control wheelchairs, televisions, or household appliances by thought alone.

Neuron passes signals to other neurons



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.

Transistor can switch neurons on and off

HUMAN COMPUTER

Human brains have taken millions of years to evolve. The modern human brain is about 30–35 percent 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.

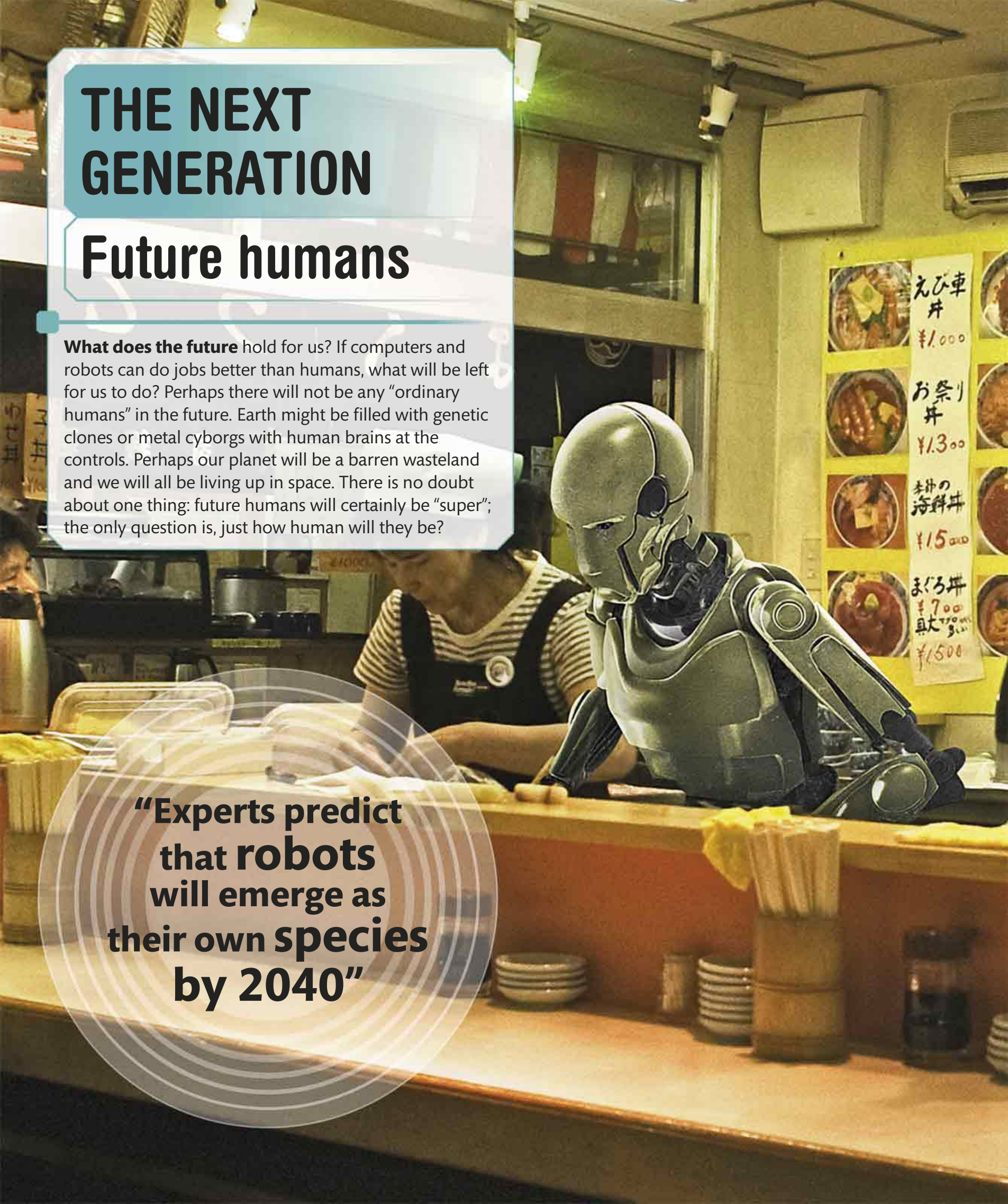
“The most powerful computers are only half as powerful as a mouse’s brain”

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 coworker, neighbor, 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.

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 fiber that extends from a *nerve cell (neuron)*. It carries electrical signals away from the cell.

BACTERIUM (PLURAL BACTERIA)

A small type of microorganism. Bacteria live everywhere. Some types cause disease in humans, but some are beneficial and help 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 move.

CAPILLARY

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

CARBOHYDRATE

A food group that includes sugars and starches that 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. 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 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 threadlike 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 fiber 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 the food entering your windpipe.

EPINEPHRINE (ADRENALINE)

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

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.

FECEES

Solid waste that is made up of undigested food, dead cells, and bacteria that are left after digestion and eliminated from your anus.

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 deoxyribonucleic acid (DNA) contained in a set of *chromosomes*. In humans there are 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.

GRAY MATTER

Brain tissue that consists

largely of the cell bodies of neurons. The outer layer of the brain is gray matter.

HEMOGLOBIN

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

HERTZ

A unit used to measure the 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 the brain and 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 color.

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

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 FIBER

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

A term for a nerve cell. Neurons carry information around your body as electrical signals.

NUCLEUS

The control center 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 esophagus during swallowing.

PROTEINS

Vital nutrients that help your body build new cells. Food 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

°C	degrees Celsius
Cal	Calories—equal to 1 kcal
cm	centimeter
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	kilometer
km/h	kilometers per hour
lb	pound
m	meter
min	minute
ml	milliliter
mm	millimeter
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 toward 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. They work in dim light but do not detect color (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 toward 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

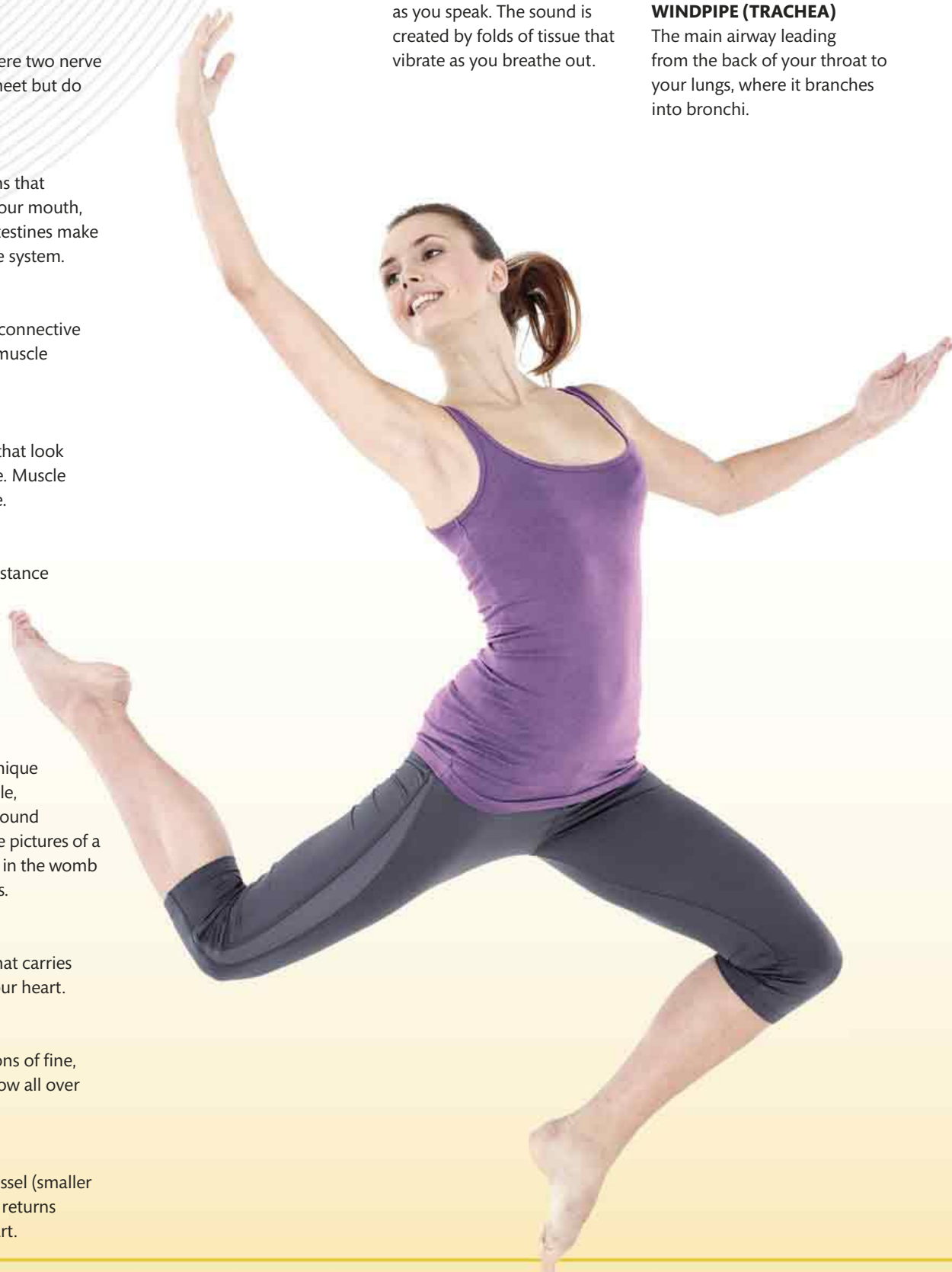
Any of the colorless blood cells that play various roles in your immune system.

WHITE MATTER

Brain tissue made up mainly of the axons (long fibers) 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.



INDEX

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

A

achilles tendon 45
adaptable humans **8-9**
adenoids 156
adrenal glands 165, 166, 167
adrenaline 166, 167
 see also epinephrine
aging 90, 183, **186-7**
airways **112-3**, 114, 118
allergies 159
altitude sickness 130
alveoli 113
amniotic fluid 175
antibodies 157, 158, 159, 160
anus 145
aorta 120, 122, 123
appendix 144
arteries 23, 120, 122, 124, 128, 152
arterioles 124
axons 55, 58, 59

B

babies 18, **174-7**, 178, 194
baby teeth 138
bacteria (germs)
 defense 79, 112, 129, 150, 156, 157, 158,
 159, 160, 161
 intestines 144, 145
 medicines 190
balance 33, 44, 50, 90, 91, **94-7**, 146, 147
bile 137, 150, 151
binocular vision **86-7**
bionic bodies **192-3**
bladder 75, 152, 153
blastocyst 172, 173
blinking reflex 68, 70
blood **128-9**, 164
 artificial 191
 breathing 112, 113, 115, 116

blood *continued*
 circulatory system 14, **120-1**
 digestive system 137, 144
 fetus 174
 heart 122, 123
 kidneys 152
 liver 150
blood cells
 aging 186
 bone marrow 37
 bones 32
 human adaptability 9
 repair 162
 see also red blood cells, white blood
 cells
blood clotting 36, 129, 151, 163
blood sugar (glucose) 124, 128, 151, 152,
 165, 166, 168
blood transfusion 191
blood vessels 14, 120, **124-5**, 128, 129
blood cells 133, 160
body temperature 24, 26
bone 36
 fetus 174
 gravity **126-7**
 nanobots 191
 pain 108
 skin 23
body temperature **24-5**, 26, 164
 blood 128
 brain 62
 human adaptability 8, 9
 reflex actions 70
 space living 189
 touch receptors 105
bone **36-7**
bone marrow 36, 37, 157
bones 13, 14, 32, 34
 aging 183, 187
 cartilage 43
 ear 32, 90, 91
 finger 28
 gravity 33
 growth 182

bones *continued*
 hormones 164
 joints 39, 41, 162
 leg 35
 muscle groups 48
 pain 108
 tendons 45
boys 19, 180, 181, 182
brain 12, 14, 54, 61, **62-3**
 aging 183, 186
 arteries 120
 balance 94, 95, 96
 binocular vision 86, 87
 bionic bodies 193
 blood gas levels 116
 body temperature 24, 25, 26
 circulation 125
 coordination **56-7**
 cranial nerves 55
 development **64-5**, 179
 embryo 174
 gravity 127
 hearing 90
 links to computers 196, 197
 memories 72, 73, 182
 movement control 44, 66, 67
 olfactory system 102, 103
 pain 108
 puberty 180
 reaction times 68
 reflex actions 71
 retina 82, 83, 84
 sleep 74, 75
 smell 102
 stress 166, 167
 taste 98, 99, 100
 touch 104, 105
brain cells 163, 191
brain stem 62, 63, 115
breastbone (sternum) 32
breathing **112-7**
 energy 146
 high altitude 9, 130
 movement 66

breathing *continued*
 muscles 44
 sleep 74, 75
 space living 8, 189
 stress 167
 vagus nerve 54
 voice 118
bronchi (airways) 113
bronchioles 113

C

cecum 144
calf bone (fibula) 33, 182
capillaries 113, 120, 124, 125, 133, 144
carbohydrates 136, 137, 147, 148
carbon dioxide 112, 113, 114, 115, 116,
 128, 132
cardiac (heart) muscle 123
carotid artery 14, 120
cartilage 32, 39, **42-3**, 90, 139, 162, 182
cell division 16, 18, 173
cells **16-7**
 apoptosis 162
 blood 9, 32, 37, 128, 162
 bone 36, 37
 cartilage 42, 43, 182
 cone 17, 82, 83, 84, 89
 DNA 18
 egg 17, 172, 173
 energy 146, 147
 epithelial 17
 fat 17
 hair 91, 92, 93, 95
 keratin 28
 light-sensitive 17
 muscle 49
 nerve 17, **58-9**, 60, 61
 olfactory receptor 102
 pancreas 191
 red blood 17, 18, **132-3**, 186,
 190, 191
 retina 82, 84
 skin 22, 23

cells *continued*
smell receptor 103
smooth muscle 17
space travel 188
sperm 17
stomach 142
taste receptor 98, 99
see also white blood cells
central nervous system 54
cerebellum 62, 63, 66, 67, 94
cerebrum 62, 63
chemosenses,
smell 102
taste 98
chewing 98, **138-9**
childhood **178-9**
chromosomes 18, 19, 186
circulation **120-1**
clavicle (collarbone) 32
cloning 195
clotting 36, 129, 151, 163
cochlea 90, 91, 93, 193
coccyx (tailbone) 33
cold detectors 70, 100
cold survival **26-7**
collagen 41, 42
colon 144, 145, 145
color vision 12, 82, 83
compact bone 36, 37, 182
computers 196, 197, **198-9**
cone cells 17, 82, 83, 84, 89
conjunctiva 78
consciousness 74
cornea 78, 79, 82, 191
coronary artery 122, 123
cough reflex 70, 118
cranial nerves 55
cytoplasm 16

D

dendrites 17, 58, 59, 61, 163, 179
dermis 22, 23
diabetes 191
diaphragm 54, 114, 117, 118
diet 12, 136, 147
digestion **136-7**
chewing 138
hormones 165
sleep 74
stomach 142
stress 167
digestive juices 136, 138, 140, 144,
157, 165

digestive system 12, 15, 74, 165
diseases 158, 194, 195
DNA **18-9**
dreaming 75
duodenum 144

E

ear bones (ossicles) 32, 38, 91
ears **90-1**
balance 94, 95, 96
bionic bodies 193
body temperature 24
cochlea 93
nervous system 14
sleep 74
touch receptors 105
egg cells 17, 172, 173
fertilized 16, **172-3**, 176
frozen 188
genes 18
multiple births 176
puberty 181
embryo 173, 174, 182, 188
emotions 61
endocrine gland system 15, 164
energy 148
circulatory system 120
food **146-7**
heart 123
hormones 165
nutrients 137
enzymes
chewing 138
digestion 136, 137
hormones 165
sleep 74
stomach 140, 142, 157
white blood cells 160
epidermis 22, 23, 104
epiglottis 98, 139
epinephrine **168-9**
exercise
breathing rates 114
circulation 125
muscles 45, 48
range of movement 40
eye color 10, 19
eyebrows 29, 49, 174
eyes 12, 14, 68, **78-85**, 191
aging 186
arteries 120
baby 174, 175
balance 94

eyes *continued*
binocular vision 86
bionic bodies 192, 193
cranial nerves 55
focusing 87, **88-9**
genetic engineering 195
muscles 45, 89
reflex actions 70, 71
sleep 74, 75
stress 167

F

face 10, 49, 55, 105, 175
fallopian tubes 173
fat
aging 183
digestion 136, 137
fetus 174
skin 23, 26
father 18, 19, 172
females 172
chromosomes 19
growth 182
ligaments 41
puberty 180, 181
vocal cords 119
femur (thighbone) 37, 39, 182
fertilized egg 16, **172-3**, 176
fibula (calf bone) 33, 182
fingernail 28, 174
fingerprints 10, **22-3**, 106, 175
fingertips 105, **106-7**
fetus 174
food 136, 142, 144, 145, **146-7**, 148

G

gall bladder 150
gene therapy 194
genes 16, 17, **18-9**, 29, 172, 173, 176, 183
genetic engineering **194-5**
germs (bacteria)
defense 79, 116, 129, 150, 156, 157, 158,
159, 160, 161
intestines 144, 145
medicines 190
girls 19, 180, 181, 182
glucose (sugar), blood 124, 128, 150, 151,
152, 166, 168
gluteus maximus muscle 44, 47
gravity 33, **126-7**
growth 147, 178, 180, 181, **182-3**
gullet (esophagus) 136, 139

gut (intestines) 15, 136, 137, **144-5**
liver 150
pain 108
repair 162
sleep 74
stress 167

H

hemoglobin 128, 129, 132
hair 10, 12, **28-9**
aging 183
body temperature 25
color 19
fetus 174
genetic engineering 195
puberty 180
replacement 162
skin 22, 23
hair cells 91, 92, 93, 95
hearing 63, 66, 67, 73, **90-3**, 183
heart 12, **122-3**
aging 186
blood 128
circulation 14, 120, 124, 125
energy 146
epinephrine 168
fetus 174, 175
gravity **126-7**
growth 182
hormones 164, 165
sleep 74
stress 167
vagus nerve 54
heart transplant 190
heartbeat
bionic bodies 192, 193
energy 146
fetus 174
movement 66
pulse 121
sleep 74
vagus nerve 54
heat detectors 100
hips 14, 32, 33, 35,
38, 39, 66
muscles 44, 45, 48,
49, 49
puberty 181
Homo sapiens 12
hormones 15, **164-5**
blood 124, 128
brain 62
hair 29

hormones *continued*
ligaments 41
liver 150, 151
puberty 180, 181
reproduction 172
stress 166, 167
human adaptability **8-9**, 188
human genome 194
humerus 32
hypothalamus 62, 164

I
iliac artery 121
iliac vein 121
immune system 15, **156-9**
inferior vena cava 120, 122
insulin 150, 151, 191
intelligence 12, 195
intestines (gut) 15, 136, 137, **144-5**
aging 187
liver 150
pain 108
repair 162
sleep 74
stress 167

J K
jawbone 14, 138
joints 13, 34, 35, **38-9**
aging 183
balance 94, 96
cartilage 43
ligaments 45
movement control 66
pain 108
range of movement **40-1**
skeleton 14, 32
wear and tear 162
jugular vein 120
keratin 23, **28-9**
kidneys 75, **152-3**, 165, 175

L
large intestine 137, **144-5**
larynx (voice box) 113, 118, 119, 139
lifespan 11, 187
ligaments 39, 40, 41, 45
light-sensitive cells 17
liver **150-1**
digestion 137
glycogen 148

liver continued
hormones 164, 165
intestines 144
stress 166
lumbar vertebrae 32
lungs 12, 15
blood 128
breathing 112, 113, 114, 115
cold survival 26
embryo 174
energy 146
growth 182
heart 122
human adaptability 9
sleep 74
sprinter 47
stress 167
lymph 15, 137, **156-7**

M
males 19, 119, 172, 180, 181, 182
medicines 190
melanin 22
memories 8, 10, 62, **72-3**, 163, 182, 183,
192
olfactory system 102
sleep 74
meninges 54, 62
mitochondria 17, 147
mother 18, 19, 172, 174, 175, 177
mouth,
breathing 114
chewing 138
digestion 136
facial muscles 49
sleep 74
stress 167
taste 98
voice 119

muscles 13, 14, 34, **44-5**
aging 183, 187
arteries 124
balance 94, 96
body temperature 24, 25
breathing 114, 115
circulatory system 120
control 57, 66, 67
cranial nerves 55
ear 90
embryo 174
energy 146, 147
exercise 40, 125
eye 45, 80, 81, 89

muscles continued
face 49
finger 28
fetus 175
freediving 112
glycogen 148
gravity 33
groups of **48-9**
growth 182, 183
gymnast **50-1**
intestines 145
joints 39
pain 108, 109
puberty 180
reaction times 68
sleep 74, 75
sprinter **46-7**
stomach 140, 141
stress 167
tendons 45
tongue 98
vocal cords 119

N
nails **28-30**, 104, 174
nanobots 190, 191
nerve cells (neurons) 17, **58-61**, 67
brain 63, 64, 163, 179
computer links 196, 197
memories 72
muscle control 66, 67
reflex actions 70, 71
repair 162
retina 82
stress 166
nerve signals (impulses, messages) 17, 54,
55, 58, 59, 61
arteries 125
balance 95
brain 62
ear 90, 91
memories 72
movement control 66
muscles 44
pain 108, 166
reaction times 68
reflex actions 70
retina 82, 84
smell 102, 103
taste 98, 99
touch 105
nervous system 14, **54-5**,
166, 167

nose,
arteries 120
bionic bodies 192
breathing 116
cartilage 43
protection 156
sleep 74
smell 103
sneezing 70, 118
touch receptors 105
voice 119
nutrients,
blood 14, 128, 129
circulation 120, 124
digestion 15, 136, 137, 144
fetus 174
hormones 165
liver 150, 151
lymph 156
repair 162

O
esophagus (gullet) 136, 139
estrogen 165
ligaments 41
puberty 181
olfactory system **102-3**
omnivorous diet 12
optic nerve 79, 82
optical illusion 87
organ of corti 91
organelles 16
organs 14
embryo 174
replacement 191
ossicles (ear bones) 32,
38, 91
ovaries 172
hormones 165
puberty 181
oxygen,
blood 14, 128, 129
breathing 15, 112, 113, 114,
115, 116
circulation 120, 124
cold survival 26
energy 146
fetus 174
high altitude 130
human adaptability 9
red blood cells 132
sprinting 47
stress 167

P

pacemaker 192, 193
pain **108-9**
 reflex actions 70
 stress 166
pain receptors 100, 104
palate 98, 138, 139
pancreas 15
 cell transplants 191
 digestion 137
 hormones 165
 intestines 144
papillae 98, 99, 100
parallax 87
parathyroid glands 164
patella (knee cap) 33
pelvis (hipbone) 14,
 32, 39
 joints 38
penis 181
peripheral nervous
 system 54
peristalsis
 intestines 145
 stomach 141
 swallowing 139
 ureter 153
peroneal nerve 55
perspective vision 87
phalanxes 33
pharynx (throat) 139
 reflex actions 70
 swallowing 138, 139
 taste 98
 voice 119
phrenic nerve 54
pineal gland 164
pinna 90
“pins and needles” 55
pituitary gland 62, 164
placenta 174
plasma 128, 129, 132
platelets 128, 129
 bone marrow 37
 clotting 163
poisons 150
posture 50
practice 67
pregnancy,
 baby brain size 179
 fetus 175
 multiple births 176
premolar teeth 138

pressure receptors 104
 balance 94
 reflex actions 70
 tongue 100
primates 12
proteins 136, 137
protists 158
puberty **180-1**
 growth 182
pulmonary artery 120, 122, 123
pulmonary vein 120, 122, 123
pulse 121, 124
pupil 71, 78

Q R

quadriceps muscles 45, 48, 49
quadruplets 176
radial artery 121
radius 32
reaction times **68-9**
receptor cells 98, 99
rectum 137, 145
red blood cells 17, **132-3**
 aging 186
 blood 128, 129
 bone marrow 37, 157
 circulation 124
 clotting 163
 DNA 18
 high altitude 130
 hormones 165
 liver 150
 nanobots 190
 transplant 191
reflex actions **70-1**
 baby 178
 fetus 174
 pain 108, 109
REM sleep 74, 75
renal artery 120, 152
renal vein 120, 152
repair and replacement **162-3**
 sleep 74
replacement body parts 190
reproduction **172-3**
 puberty 180
respiratory system 115
 high altitude 130
 voice 118
 see also breathing
retina 78, 79, 82, 84
 bionic bodies 192
ribs 32, 114, 115

robots 193, **198-9**
 surgery 190
rod cells 17, 82, 84, 89

S

sacral plexus 54
sacrum 33
saliva 139
 chewing 138
 digestion 136
 protection 156
 stress 167
 taste 98
salivary glands 138
salts 129, 136, 144
saphenous vein 121
sartorius muscle 14
scapula (shoulder blade) 32
 muscles 45
sciatic nerve 55
sebum 156
semicircular canals 91, 95
sense organs 14
 cranial nerves 55
senses 8, 57
 balance **94-7**
 hearing **90-3**
 pain **108-9**
 sight **78-89**
 sleep 74
 smell **102-3**
 taste **98-101**
 touch **104-7**
sensory area of brain 63
sensory homunculus 105
sensory nerves,
 pain 108
 reflex actions 71
sex chromosomes 19
shinbone (tibia) 33
 growth 182
 joints 39
shivering 25
shoulder blade (scapula) 32
 muscles 45
sickness 190
sight **78-89**
 brain 61, 63
 memories 72, 73
singing 118
skeleton 14, **32-5**, 36
 growth 182
skin **22-3**
 aging 183, 187
 artificial 190
 balance 94, 95, 96
 body temperature 24, 25
 fingertip 107
 keratin **28-9**
 pain 108
 protection 156, 158
 reflex actions 70
 repair 162
 touch receptors 104, 105
skin color 10, 19
skull 33
 arteries 120
 brain 62
 joints 38
sleep **74-5**
 child 179
 hormones 164
 reaction times 68
small intestine 15, 137, 140, **144-5**
smell **102-3**
 memories 72, 73
 sleep 74
sneezing 70, 118
snoring 74
sounds,
 hearing 32, 61, 90, 91
 memories 72
 voice **118-9**
space station living 189
spacesuits 189
speach 63, 119
sperm 17, 172, 173
 frozen 189
 genes 18
 multiple births 176
 puberty 181
sphincters, stomach 140
spinal column 32
spinal cord 54, 55
 brain 62
 pain 108, 109
 reflex actions 70
spinal nerves 54
spine 33, 38
spleen 156
spongy bone 36, 37, 182
stem cells 16, 195
sternum (breastbone) 32
stomach 15, **140-3**
 digestion 136, 137,
 144, 145
 fetus 174

stomach *continued*
hormones 164, 165
protection 157
sleep 74
stress 167
strength 51
stress **166-7**
dreaming 75
stretch sensors 94, 95
sugar (glucose), blood 124, 128, 150, 151,
152, 166, 168
sugars 146, 147, 148
superior vena cava 120, 122
suspended animation 189
swallowing **138-9**
sweat 149, 156
sweat glands 22, 23, 24
sweat pores 107
synapses 59
memories 72
reflex actions 71
systems of the body **14-5**

T

tailbone (coccyx) 33
talking 118
baby 178
tarsals 33
taste **98-101**
aging 186
memories 72, 73
taste buds 98, 99, 100, 101, 105
tears 79
teeth 12, 138
temperature **24-5**, 26, 164
blood 128
brain 62
human adaptability 8, 9
reflex actions 70
space living 189
touch receptors 105
temperature receptors 104
tendons 45
exercise 40
facial muscles 49
testes 165, 172
puberty 181
testosterone 165
puberty 181
thalamus 66, 67
thighbone (femur) 37,
39, 182
thigh muscles 44, 48, 49

thoughts 12, 61, 62, 72
sleep 74
throat (pharynx) 139
reflex actions 70
swallowing 138, 139
taste 98
voice 119
thumb 38, 45
thymus gland 15
hormones 164
protection 156
thyroid gland 164, 165
tibia (shinbone) 33
growth 182
joints 39
tibial artery 121
tibial nerve 55
tibial vein 121
ticklishness 55
toddlers 178
toes 33
fetus 174, 175
joints 35, 39
touch receptors 105
tongue **100-1**
chewing 138
genes 19
muscles 48
swallowing 139
taste 98, 99
touch receptors 105
toothache 54
touch sense 22, 23, **104-5**
balance 95
fingertips 106
memories 72
pain 108, 109
toxins 150
trachea (windpipe) 112, 113, 114, 115
coughing 118
triceps muscle 47
triplets 176
twins 10, 176
tympanic membrane 91

U

ulna 32
ulnar nerve 54
ultrasound scan 175
umbilical cord 174, 175
urea 128
ureters 152, 153
urethra 153

urine 152, 153, 166
uterus (womb) 172, 173, 174
fetus 175

V

vagus nerve 48
valves
heart 122, 123
veins 125
veins 120, 125, 128
heart 122
kidneys 152
skin 23
vena cava 120, 122
ventricle 122, 123
venules 125
vernix 174
vertebrae 32, 33
vestibular nerve 91
villi 144
viruses 158
vision 12, **86-7**
movement control 66
vitamins 137, 150, 151
vitreous humour 78, 79
vocal cords 118, 119
puberty 180
voice **118-9**
voicebox (larynx) 113,
118, 119
chewing 139
puberty 180
voluntary movement 66
vomiting 141

W

walking,
baby 178
bionic bodies 192
wastes,
blood 128
breathing 112, 114
circulation 120, 124
hormones 165
kidneys 152, 153
liver 150
lymph 156
water,
bones 32
digestion 137
hormones 165
intestines 144, 145

water *continued*
kidneys 152, 153
sweat 149
wax, ear 90
whispering 118
white blood cells 128, 129, **160-1**
bone marrow 37
broken bones 36
hormones 164
immune system 158, 159
liver 150
lymph 156, 157
repair 162
windpipe (trachea) 112, 113, 114, 115
coughing 118
womb (uterus) 172, 173, 174
fetus 175
women 180
wrist joints 32, 38
muscles 45

XYZ

X chromosomes 19
xenotransplantation 191
Y chromosomes 19
yawn reflex 70
zona pellucida 172

ACKNOWLEDGMENTS

Dorling Kindersley would like to thank Jane Parker for the index; Katie John and Steve Setford for proofreading; Samina Ali and Ethen Carlin for design assistance; Natasha Rees for additional design; Adam Brackenbury for creative retouching; Gill Pitts and Kaiya Shang for editorial assistance; Chris Rao, John Spiliotis, and Alexandra Ashcroft for additional consultancy; Annabel Hobbs for hair and makeup, and for modelling: Grace Derome, Kate Byrne, Laura Cathryn, Thomas Snee, and Dhillon Boateng.

DK India would like to thank Divya P R, Vaibhav Rastogi, and Riti Sodhi for design assistance; Kanika Mittal, Heena Sharma, Vikas Chauhan, and Arun Pottirayil for assistance with artworks; Dharini Ganesh, Himani Khatreja, and Sonia Yooshing for editorial assistance.

Picture Credits

The publisher would like to thank the following for their kind permission to reproduce their photographs:

(Key: a-above; b-below/bottom; c-center; f-far; l-left; r-right; t-top)

1 Fotolia: He2 (c). **2-3 Corbis:** TempSport / Dimitri lundt (b). **3 Fotolia:** He2 (c). **4 Corbis:** Demotix / Pau Barrena (tr). **6 Photoshop:** PYMCA (tr). **Science Photo Library:** Eye Of Science (bl). **7 Dreamstime.com:** Yuri_arcurs (bl). **Science Photo Library:** Carl Goodman (tr). **8 Getty Images:** Gallo Images / Danita Delimont (cl). **NASA:** (bc). **9 Dreamstime.com:** Anatoliy Samara (cra); Seqoya (crb). **Getty Images:** Aurora / David McLain (tc). **10 Getty Images:** E+ / azgAr Donmaz (bl). **10-11 Corbis:** Blend Images / John Lund (c). **11 Corbis:** (tc). **12-13 Science Photo Library:** Pasieka (c). **15 Science Photo Library:** Simon Fraser (t). **16 Science Photo Library:** Dr. Torsten Wittmann (bc). **17 Science Photo Library:** Steve Gschmeissner (crb). **18 Dreamstime.com:** Ron Chapple (bc). **18-19 Dorling Kindersley:** Zygot Media Group (c). **19 Dreamstime.com:** Ruslan Nassyrov (crb). **Science Photo Library:** Power And Syred (tc). **23 Dreamstime.com:** Jun Mu (tc/Red Fingerprint); Vince Mo (tc/Blue Fingerprint). **Science Photo Library:** Power And Syred (crb). **24 Alamy Images:** imageBROKER (c).

Science Photo Library: Tony Mcconnell (cra). **25 Dreamstime.com:** Alxyago (c); Tyler Olson (cr). **26-27 Getty Images:** Stone / David Trood. **29 Dreamstime.com:** Drx. **30-31 Getty Images:** AFP. **32 Photoshop:** Picture Alliance / Rolf Vennenbernd (crb). **33 NASA:** (crb). **34-35 Getty Images:** AFP. **36 Science Photo Library:** Steve Gschmeissner (crb). **38-39 Corbis:** BJI / Blue Jean Images (t). **39 Dreamstime.com:** Brenda Carson (bl). **40-41 Corbis:** TempSport / Dimitri lundt. **42-43 Science Photo Library:** Steve Gschmeissner. **44 Science Photo Library:** Martin Oeggerli (cl). **46-47 Corbis:** Pete Saloutos. **48 Fotolia:** Gelpi (crb). **49 Dreamstime.com:** Alexsutula (tr). **50-51 Corbis:** Gerlach Delissen. **56-57 Corbis:** Paul Souders. **58 Science Photo Library:** Nancy Kedersha (cra). **60-61 Science Photo Library:** Thomas Deerinck, NCMIR. **63 Science Photo Library:** Tom Barrick, Chris Clark, SGHMS (bl). **64-65 Corbis:** Demotix / Pau Barrena. **66 Getty Images:** Cultura / Hybrid Images (cra). **67 Science Photo Library:** Don Fawcett (crb). **68-69 Getty Images:** Moment Select / Fredrik Lonnqvist. **70 Dreamstime.com:** Lenanet (clb). **71 Pearson Asset Library:** Trevor Clifford / Pearson Education Ltd (tc). **72 Dreamstime.com:** Monkey Business Images Ltd (crb). **73 Corbis:** Allana Wesley White (cr). **Dreamstime.com:** Ljupco Smokovski (crb). **74-75 Getty Images:** Topic Photo Agency (cb). **75 Getty Images:** Photographer's Choice / Bob Elsdale (cr). **79 123RF.com:** martinak (tc). **80-81 Corbis:** Simon Marcus. **83 Dreamstime.com:** Eveleen007 (tl). **84-85 Science Photo Library:** Omikron. **86-87 Dorling Kindersley:** Duncan Turner (c). **87 Alamy Images:** Objowl (br). **88-89 Getty Images:** Aflo / Enrico Calderoni. **92-93 Science Photo Library:** Steve Gschmeissner. **95 Dreamstime.com:** Grigor Atanasov (cra). **96-97 tim-mckenna.com:** 98 Corbis: Holger Scheibe (l). **99 123RF.com:** tang90246 (tr). **100-101 Science Photo Library:** 103 Dreamstime.com: Atholpady (crb). **Science Photo Library:** Steve Gschmeissner (tl). **106-107 Science Photo Library:** Martin Dohrn. **109 Corbis:** Tim Clayton / TIM CLAYTON (cb). **112-113 Getty Images:** Stone / Michele Westmorland. **114 Getty Images:** Visuals

Unlimited / Dr. David Phillips (cra). **118-119 Science Photo Library:** Dr. Gary Settle (t). **119 Dreamstime.com:** Martinmark. **120 Science Photo Library:** Zephyr (tl). **123 Science Photo Library:** (tl, ca). **124 Getty Images:** Visuals Unlimited, Inc. / Thomas Deerinck (bc). **126-127 Getty Images:** Iconica / Tyler Stableford. **128 Dreamstime.com:** Zzvet (br). **130-131 Giri Giri Boys/Yusuke Sato:** 132-133 Science Photo Library: CDC / Science Source. **140 Science Photo Library:** Dr. K.F.R. Schiller (clb). **142-143 Science Photo Library:** Eye Of Science. **144 Science Photo Library:** University "La Sapienza", Rome / Professors P. Motta & F. Carpino (bl). **145 Science Photo Library:** (tr). **147 Dreamstime.com:** Diana Valujeva (l). **Science Photo Library:** Bill Longcore (tr). **148-149 Dreamstime.com:** Klemen Misic. **156 Science Photo Library:** Custom Medical Stock Photo / Richard Wehr (crb); Professors P.M. Motta, K.R. Porter & P.M. Andrews (tr). **157 Science Photo Library:** Prof. P. Motta / Dept. Of Anatomy / University "La Sapienza", Rome (c). **160-161 Science Photo Library:** 162 Science Photo Library: Steve Gschmeissner (clb). **162-163 Getty Images:** The Image Bank / PM Images (c). **163 Dreamstime.com:** Bidouze Stéphane (bl). **Science Photo Library:** UCLA / Nancy Kedersha (tc). **166-167 Photoshop:** PYMCA (t). **166 Corbis:** Eleanor Bentall (b). **168-169 Corbis:** dpa / Daniel Ramsbott. **175 Dreamstime.com:** Giovanni Gagliardi (cla). **176-177 Alamy Images:** Inspirestock Inc.. **178 Alamy Images:** Tetra Images (crb). **Getty Images:** Asia Images / Yukmin (clb). **179 Camera Press:** Ian Boddy (cl). **Dreamstime.com:** Yuri_arcurs (r). **180 Corbis:** Hiya Images (bc). **PNAS:** 101(21):8174-8179, May 25 2004, Nitin Gogtay et al, Dynamic mapping of human cortical development during childhood through early adulthood © 2004 National Academy of Sciences, USA (tl). **181 Dreamstime.com:** Christine Langerpüsichel (br). **182-183 Science Photo Library:** David Gifford (Seven Ages of Man). **183 Corbis:** Reuters / Andy Clark (tc). **186-187 Corbis:** Imaginechina (c). **186 Science Photo Library:** Pasieka (bc). **188-189 Science Photo Library:** Christian Darkin (t). **188 ESA:** ÖWF / P. Santek (cr). **Science Photo Library:** (bc).

189 NASA: Rick Guidice (bl). **Science Photo Library:** Volker Steger (bc). **190 Corbis:** Cornell / Lindsay France (bl). **Science Photo Library:** Klaus Gulbrandsen (c). **192 Getty Images:** (cla). **192-193 Dorling Kindersley:** Medimation (b). **194 Corbis:** Waltraud Grubitzsch / epa (clb). **194-195 Science Photo Library:** Hannah Gal (c). **195 Science Photo Library:** Bluestone (tc). **196 Corbis:** Blend Images / Colin Anderson. **197 Science Photo Library:** Mpi Biochemistry / Volker Steger (c); Philippe Psaila (tc). **198-199 Getty Images:** The Image Bank / SM / AIUEO