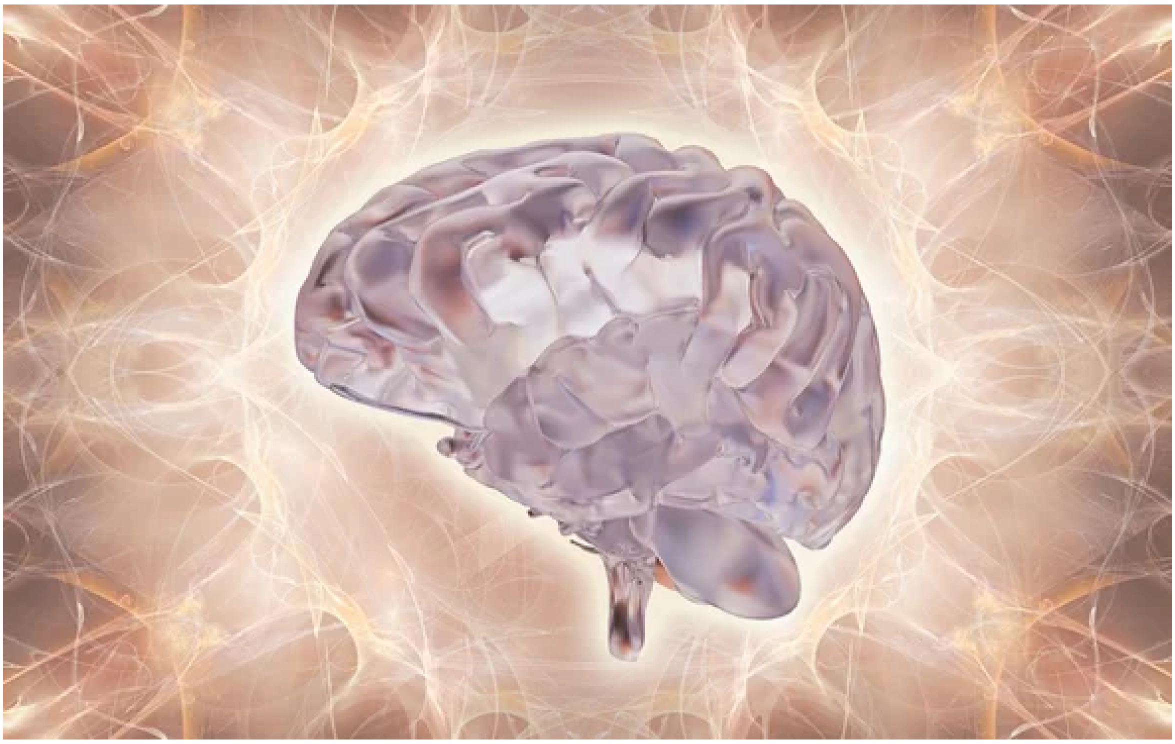
EVOLUTION

What Makes the Human Brain Special

Parts of the brain involved in language and cognition have enlarged greatly over an evolutionary timescale

By Chet C. Sherwood, Mesa Schumacher | Scientific American September 2018 Issue



Credit: Donald Iain Smith Getty Images

Humans are off the scale. Modern human brains are about threefold larger than those of our earliest hominin ancestors and living great ape relatives. Across animals, brain size is tightly correlated with body size. But humans are the extreme outlier when gauged against this typical scaling relation. The average adult human brain is roughly three pounds, which is approximately 2 percent of body size. But it consumes an outsized 20 percent of the body's energy budget because of high levels of electrical activity by neurons and the metabolic fuel it takes to transmit chemical signals from one brain cell to the next.

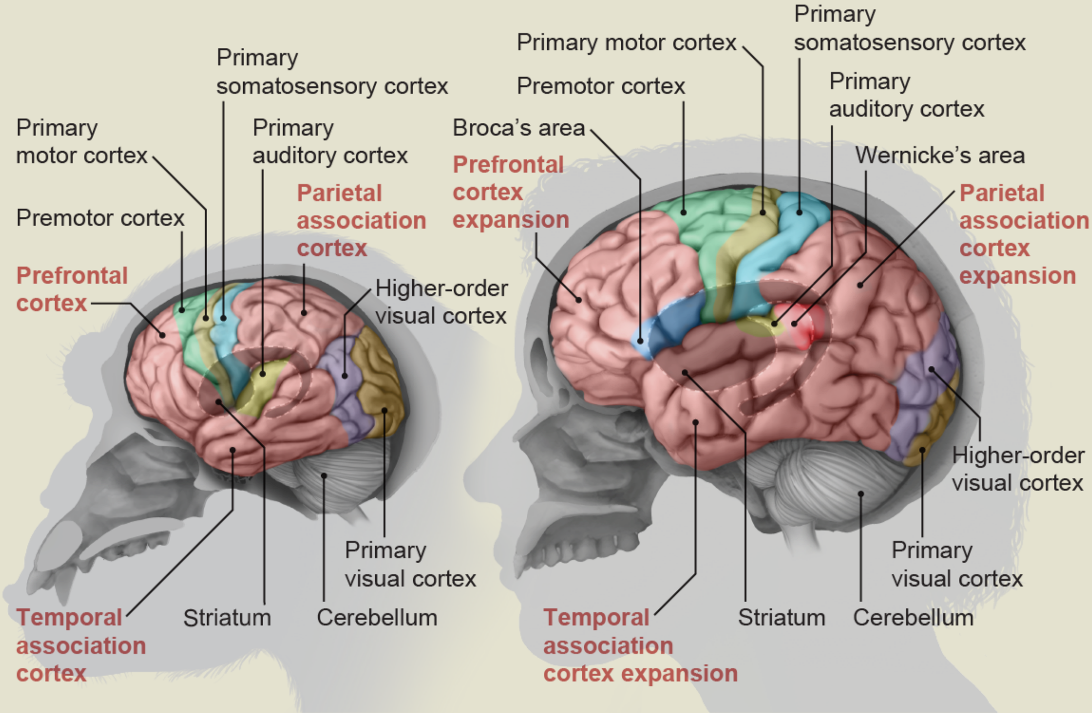
Detailed comparisons of human brains with those of our close living primate relatives, including chimpanzees, have shown that the parts of the cerebral cortex

involved in higher-order cognitive functions, such as creativity and abstract thinking, have become especially enlarged. These cortical areas, known as association regions, mature relatively late in postnatal development. Some of the long-range neural connections that link these association areas to one another and to the cerebellum (the latter plays a role in voluntary movement and learning new skills) are more numerous in human brains as compared with other primates. These human-enhanced networks are loci for language, toolmaking and imitation. Even ancient reward systems in a subcortical area called the striatum, a hub of activity for the brain-signaling molecule dopamine, appear to have been reshaped in human brain evolution. That change most likely increases attention to social signals and facilitates language learning.

Where did our big brains come from? The hominin fossil record points to a general trend toward increased cranial capacity during the past six million years or so. That is when our lineage split from the last common ancestor we shared with chimpanzees and bonobos. Scientists consider a constellation of interrelated features of human biology to be associated with our large brains—slower growth through the stages of childhood, a longer life span, and more involvement in raising offspring by fathers and grandparents to assist mothers. Extended brain growth after birth means that significant events that lay the groundwork for cognition take place in a rich social and ecological context.
Another clue to what makes us different from chimpanzees and other intelligent species comes from compelling research that has uncovered genetic and molecular changes that occurred during the long course of the brain's evolution. A look at some of the distinctive features of the human brain follows.

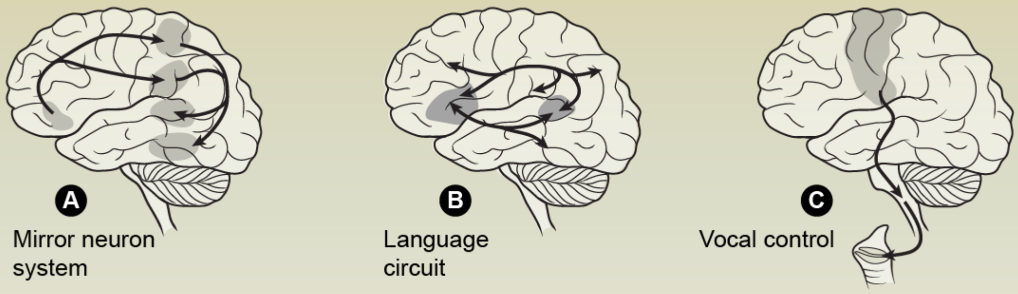
REGIONAL EXPANSION

Brain areas responsible for higher cognitive functions grew disproportionately in humans compared with the same regions in chimpanzees—among them, the prefrontal, temporal association and parietal association cortices.



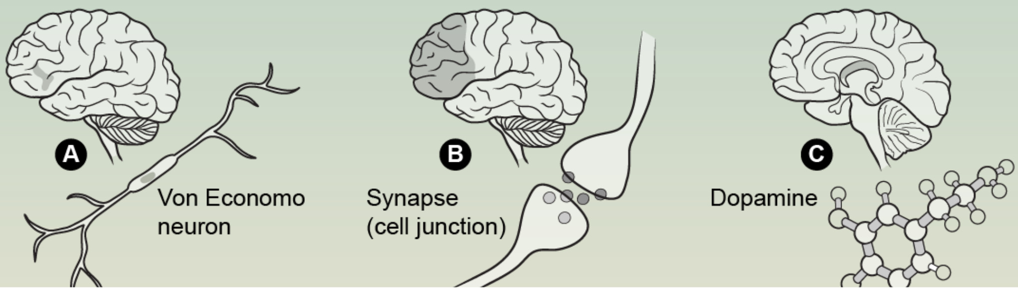
CIRCUITS

The mirror neuron system, activated when viewing the actions of others, has intricate circuitry in humans **A**. Expanded connections between two sites—Wernicke's and Broca's areas—form a vital circuit for language processing **B**. A link from the motor cortex to the brain stem coordinates the larynx muscles, a circuit absent in chimpanzees and macaques **C**.



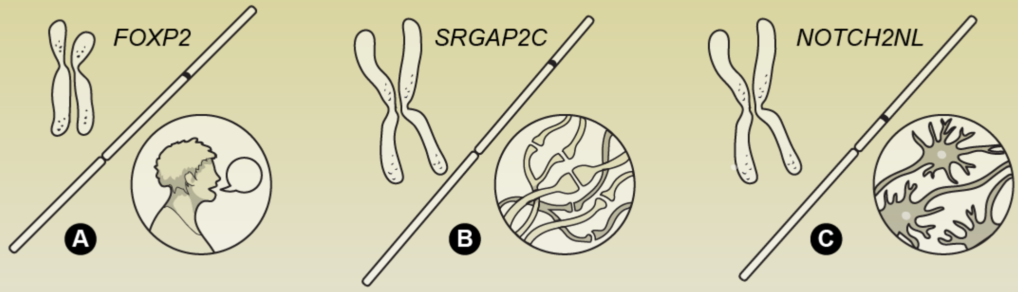
CELLS

Von Economo neurons, which are pivotal in socialemotional brain circuits, are bigger in humans **A**. RNA that carries messages to instruct cells to make proteins is more active in the synapses of the prefrontal cortex (*dark area*) than it is in other primates **B**. Cells produce more of the neurotransmitter dopamine in the striatum. Dopamine is involved in various cognitive functions **C**.



GENES

The variant of the *FOXP2* gene found in humans plays a role in vocal learning **A**. *SRGAP2C*, a unique duplicate of *SRGAP2* that is found only in humans, increases the density of neural connections **B**. A human version of a gene called *NOTCH*, known as *NOTCH2NL*, has three copies and aids in the production of neurons **C**.



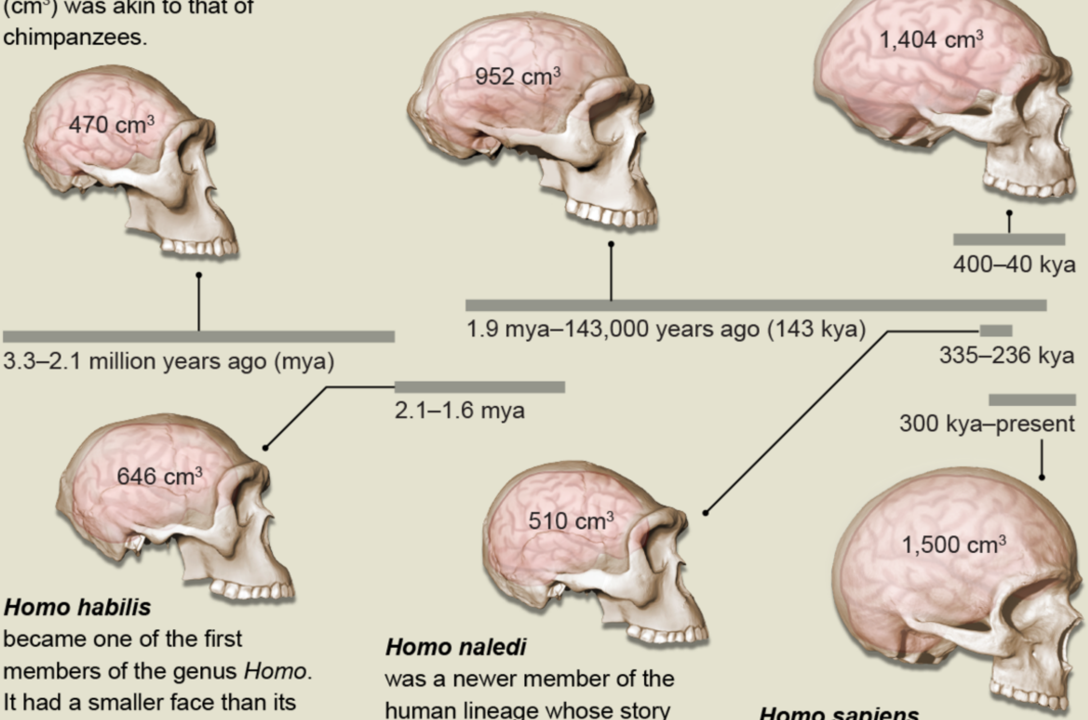
BIG BRAINS GOT US HERE

The last common ancestor that humans shared with chimpanzees and bonobos lived from six million to eight million years ago. After the two lines split, a number of evolutionary adaptations occurred: bipedalism, stone toolmaking and, notably, an increase in brain size in certain hominin species—a process that gained momentum as time passed.

Australopithecus africanus combined human and ape features. Its brain volume of 470 cubic centimeters (cm^3) was akin to that of chimpanzees.

Homo erectus distinguished itself as a toolmaker, crafting hand axes and expanding its home environment outside of Africa.

Neandertal lived alongside our species and was an avid hunter, tool and fire user. Its braincase, at 1,404 cm^3, was comparable in volume to our own.



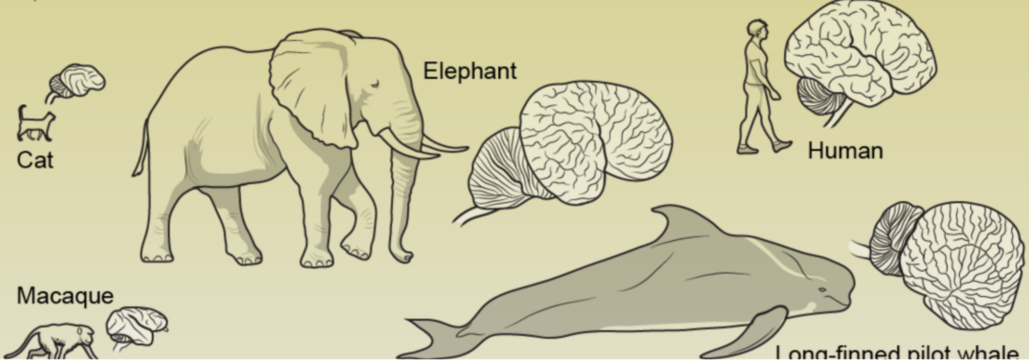
Homo habilis became one of the first members of the genus *Homo*. It had a smaller face than its ancestors and developed frontal areas linked to language.

Homo naledi was a newer member of the human lineage whose story demonstrates that evolution does not always move in straight lines. Its smaller braincase was 510 cm^3.

Homo sapiens evolved some 300,000 years ago. Our brain shape is spherical, or globular, because of the rounded shape of the parietal area and the cerebellum.

BRAIN VS. BODY SIZE

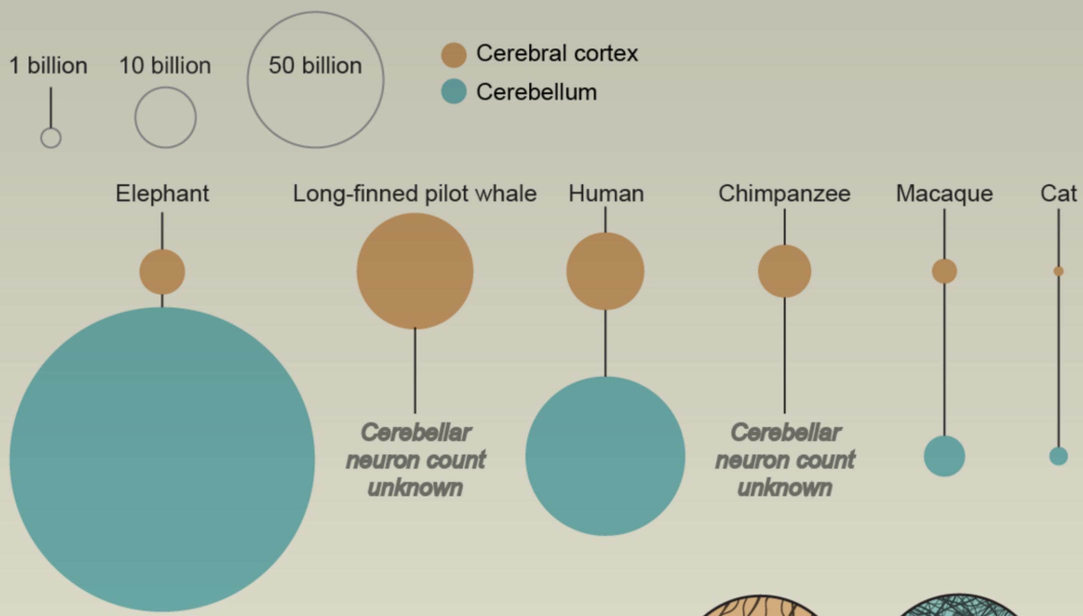
Humans have a large brain compared with its expected dimensions for their body mass. The encephalization quotient (EQ), as it is known, is 1 if the brain/body mass ratio meets expectations. Humans have an EQ of 7–8; EQs for long-finned pilot whales are 2–3; elephants are 1–2; macaques are 2; and cats are 1.



NEURON NUMBER

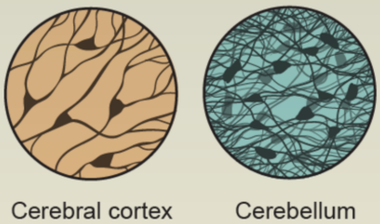
A much scrutinized measure of brainpower has to do with the number of an animal's neurons—and where they are located. Humans have more neurons in the cerebral cortex, 16 billion, than almost all other mammals, although the long-finned pilot whale has more.

Circle area shows number of neurons



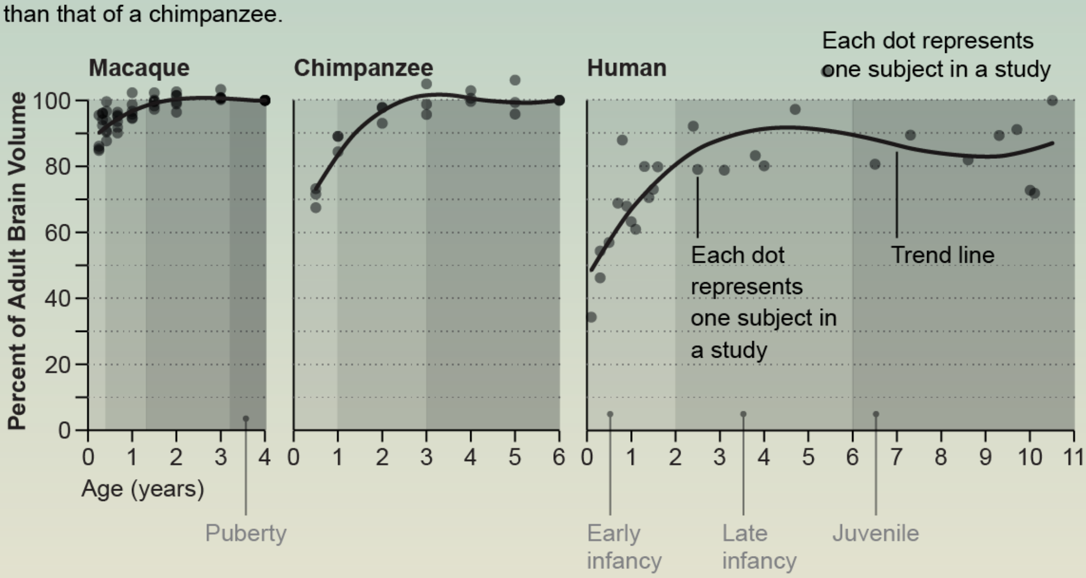
PACKING IN THE BRAIN CELLS

In humans, the cerebral cortex makes up 82 percent of the brain's mass but contains only 19 percent of the total neurons, whereas the cerebellum holds 80 percent or so of the neurons but only occupies 10 percent of its mass.



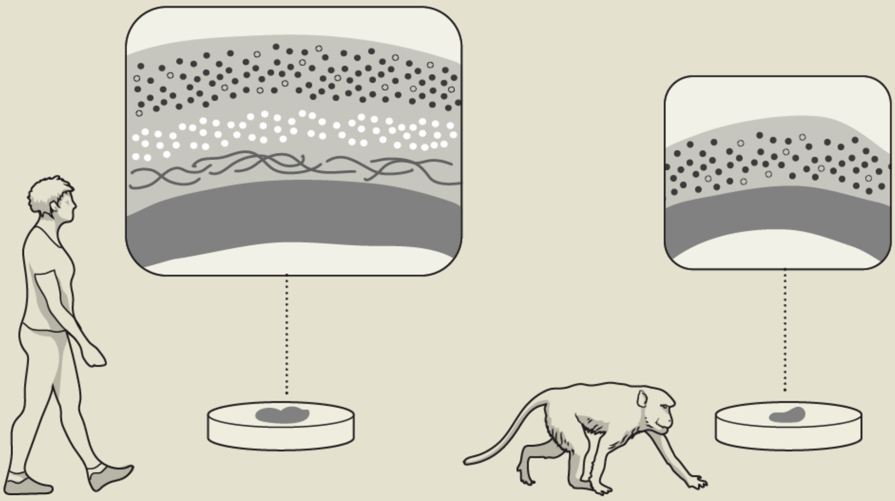
HOW OUR BRAINS GROW

Compared with other primates, human babies have brains that are underdeveloped, grow more rapidly in the first year after birth, and then level off years later with a volume about three times larger than that of a chimpanzee.



MINI BRAINS

Supplying nutrients to groups of stem cells in a lab dish allows them to grow into mini brains. These cerebral organoids, as they are called, consist of entire brain regions, such as the cortex of a human or a monkey (*cross-sectional views*). These ingenious research tools afford an opportunity to compare the activity of genes and neural circuit development in organoids with the working of actual brains in humans, nonhuman primates and other species, ultimately providing a clearer picture of what makes us unique.



Credit: Mesa Schumacher; Sources: "Developmental Patterns of Chimpanzee Cerebral Tissues Provide Important Clues for Understanding the Remarkable Enlargement of the Human Brain," by T. Sakai et al., in *Proceedings of the Royal Society B,* Vol. 270; February 22, 2013 (*brain area expansion*); "Mammalian Brains Are Made of These: A Dataset of the Numbers and Densities of Neuronal and Nonneuronal Cells in the Brain of Glires, Primates, Scandentia, Eulipotyphlans, Afrotherians and Artiodactyls, and Their Relationship with Body Mass," by S. Herculano-Houzel et al., in *Brain, Behavior and Evolution*, Vol. 86, Nos. 3–4; December 2015 (*human and macaque neuron numbers*); "Dogs Have the Most Neurons, though Not the Largest Brain: Trade-Off between Body Mass and Number of Neurons in the Cerebral Cortex of Large Carnivoran Species,"

by D. Jardim-Messeder et al., in *Frontiers in Neuroanatomy*, Vol. 11, Article No. 118; December 2017 (*cat neuron number*); "Quantitative Relationships in Delphinid Neocortex," by H. S. Mortensen et al., in *Frontiers in Neuroanatomy*, Vol. 8, Article No. 132; November 2014 (*pilot whale neuron number*); "Cortical Cell and Neuron Density Estimates in One Chimpanzee Hemisphere," by C. E. Collins et al., in *PNAS*, Vol. 113, No. 3; January 19, 2016 (*chimpanzee neuron number*); "Human Evolutionary History," by E. K. Boyle and B. Wood, in *Evolution of Nervous Systems*. Second edition. Edited by J. H. Kaas. Academic Press, 2017 (*hominin evolution*); Smithsonian National Museum of Natural History (*hominin species time line*)

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