Time to rethink the idea that our 'big' brains make us special, says **Alison Motluk**

It's not what you've got...

OVERSIZED brains are to humans what trunks are to elephants and elaborate tail feathers are to peacocks – our defining glory. What would we be without our superlative, gargantuan, neuron-packed brains? Like Donald Trump without his towers, Simon Cowell without his sneering put-downs or Bridget Jones without her diaries. We would just be ordinary primates. Unquestionably smart ones, of course, just not special.

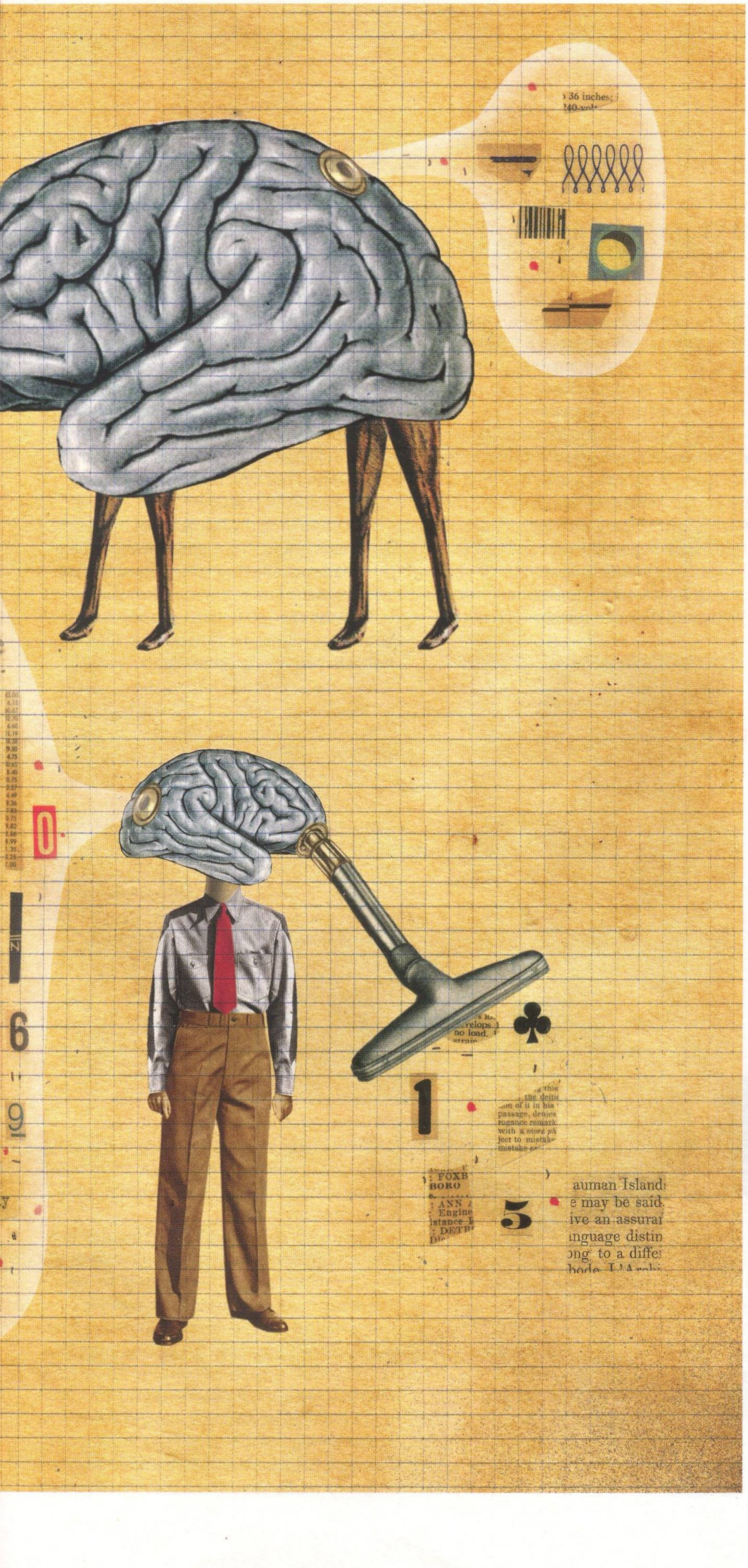
Uncomfortable as it is to contemplate, it is looking increasingly likely that our brains are not something to write home about after all. One group of researchers has scrutinised the primate archaeological record and concluded that the human brain has evolved just as would be expected for a primate of our size. Meanwhile, a biologist who has compared the number of neurons in the brains of all sorts of animals says there is nothing special about the human brain compared with other primates. No one is doubting the fact of human intelligence, but they say it can no longer be attributed to a "supersized" brain. Humans, apparently, are no more than ordinary primates with ordinary-sized brains.

These findings undermine a fundamental and long-standing belief about our place in the kingdom of life: that *Homo sapiens* is the greatest species ever to grace the Earth and that we have become the greatest because our brains are the best ever to have evolved. Admittedly, justifying this assertion has taxed our self-professed ingenuity. Clearly ours is not the biggest brain on the planet in absolute terms – whales and elephants outdo us by up to six times – but we counter this by arguing that bigger animals are bound to have bigger brains. And if you take body size into account our brain is exceptionally large, as much as seven times larger than those of other mammals (*Science*, vol 121, p 447). The underlying assumption is still that when it comes to intelligence, brain size matters. But does it?

Suzana Herculano-Houzel at the Federal University of Rio de Janeiro in Brazil decided to tackle our superiority complex head-on. "I was trained in evolution," she says. "I looked at the assertion about the human brain and how it's larger than expected and better. I thought: 'That can't be right'. Why do we believe that evolution applies to everybody except us?" She suspected that instead of being special, humans might just be part of a group of species that have particularly efficient brains.

Herculano-Houzel was struck by the fact that, although in general, bigger-brained creatures tend to be more versatile and creative, the correlation does not seem to hold up across taxonomic orders. Consider hoofed mammals – the ungulates – and primates. Cows and horses have brains four or five times larger than monkeys, but monkeys have abilities that are clearly more complex. Similarly, the capybara, a giant Amazonian rodent, cannot do with its 75-gram brain what

DAVE PLUNKERT



a capuchin monkey can do with its more modest cerebral endowment of just 52 grams.

In the past, such differences were explained away by the fact that larger brains are attached to larger bodies, the assumption being that the bigger an animal, the larger the individual neurons in its brain, meaning fewer of them can be packed into any given brain volume. It was also assumed that the bigger the brain, the more space was taken up with the hardware for transmission in the form of longer, thicker and better insulated neural pathways. As a result, a 65-kilogram capybara might still have far less raw mental processing power than a 4-kilogram capuchin monkey.

Herculano-Houzel thought there might be more to it than that. She suspected that the brains of animals in different orders might be constructed along different lines. Going directly to the heart of the matter, she wanted to know exactly how many neurons are to be found in any given brain and whether human brains are exceptional within their order.

"The human brain is nothing more than a linearly scaled up primate brain"

It is commonly stated that the human brain contains 100 billion neurons. However, when Herculano-Houzel tried to trace the origin of this "fact" she was astonished to learn that no one had actually counted them. "These were ballpark figures," she says. As for glia, the brain's support cells, rumour had it that in humans they outnumbered neurons 10 to 1. Again, no one had ever bothered to find out if this was true. This is partly because counting brain cells is a time-consuming business. Most people who have tried used the stereological method, which involves counting neurons in thin slices of brain, hoping the slices chosen have a representative number of cells, and then extrapolating the neuron content of the entire brain. Herculano-Houzel thought she could do better. She has a background in biochemistry and had seen other cell

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types quantified using a method called the "isotropic fractionator". She decided to apply the same technique to brains.

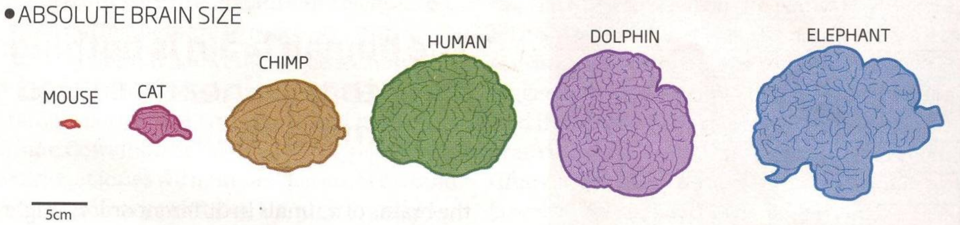
Her first brain came from a mouse. After fixing the brain with formaldehyde, she soaked it in a saline detergent solution, which broke down the cell membranes but left the nuclei intact. "Basically, I am turning fixed brains into soup," she says. After agitating the suspension to distribute the nuclei evenly, she took tiny samples and counted nuclei. Not only was the process quick – it took just 30 minutes – but she was confident her small samples were representative, because the nuclei had been evenly distributed. To figure out what proportion of the cells were neurons, she used a labelling antigen called NeuN, which reacts with and stains neuron-specific nuclear proteins. From there, she simply multiplied up from her sample size to the full volume of her brain soup (*Proceedings of the National Academy of Sciences*, vol 103, p 12138).

> **"It is the body size of the gorilla, rather than the brain size of the human, which is the outlier"**

After the mouse, Herculano-Houzel studied a range of other rodents: hamsters, guinea pigs, rats, agoutis and capybaras. She found that as size increased, there were more neurons and more glia, and also that individual neurons got bigger. So among rodents it appears that bigger brains tend to have more raw processing power, and that body size is also a factor, with bigger animals tending to have bigger neurons and therefore requiring bigger brains. These findings reflect long-held assumptions about brain size. But would they extend to primates?

Who's the cleverest of them all?

Inferring intelligence from brain size is questionable, not least because the relative sizes of brains change dramatically depending on how they are measured



EQ = actual brain mass, divided by the brain mass you would expect for a typical mammal of that body size

SOURCE: TRENDS IN COGNITIVE SCIENCES, VOL 9, P 250

To find out, Herculano-Houzel first went through the same process with the brains of six different primates, including marmosets, owl monkeys, squirrel monkeys and macaques. As she had suspected, primate brains were different. Larger brains did not have larger neurons, for instance, and there were many more neurons per volume of brain than she had found in rodents, so even if a rodent brain and a primate brain were the same size, the primate brain would have more neurons. Put another way, if a rodent had the same number of neurons as a primate, its brain would be around six times the size. "That's one of our key findings," she says. "The rules are different."

Before applying the fractionator method to a human brain, Herculano-Houzel and her team made a prediction. Based on what they knew from the other primates they had studied, they estimated that a primate with the average human body mass of 70 kilograms should have a brain of about 1300 grams, containing about 90 billion neurons, not far off the oft-quoted 100 billion. When they did actual counts, using the brains of a 70-year-old and three 50-year-old males, they found they were pretty close: the brains weighed an average of 1500 grams and contained 86 billion neurons. "It's what you'd expect for a primate brain of this size," she says. The human brain, they concluded in a paper published last year, is nothing more than "a linearly scaled-up primate brain" (*The Journal of Comparative Neurology*, vol 513, p 532).

Bigger is better?

That paper was the first blow to our self-declared specialness. Then, early this year, another paper, this time looking at the evolution of brain and body sizes among primates, came to a similar conclusion. "Human brains are not that unusual compared to other primates," says Nicholas Mundy at the University of Cambridge, who led the new research.

It is another dearly held belief that, as primates evolved, their brains got inexorably bigger, and that bigger meant better. In the first study to reconstruct brain evolution across all primates, Mundy and his colleagues evaluated evidence from 37 existing and 23 extinct primate species. They found that along most branches of the primate family tree, brains did tend to get larger, both in absolute terms and relative to body size. However, they were surprised to find that there were instances where brain size has declined within

Well connected

The finding that big brains are not necessarily better (see main story) comes as no surprise to Lars Chittka of Queen Mary, University of London, who studies bees. Bees' brains are only 1 cubic millimetre with a mere million neurons, yet bees can build complex nests, take care of their brood, defend their colony and reach consensus about where to build a new home. One study has even found that they can learn faster than vertebrates, including human infants (*Animal Learning and Cognition* by John M. Pearce, p 11). Instead of marvelling at the bees' abilities, however, the researchers discarded the test as a measure of intelligence. "There may be good reasons to be uncomfortable with equating learning speed with intelligence," says Chittka, "but that large-brained mammals don't top the chart shouldn't be one of them."

He believes scientists have often been dismissive of insect abilities simply because insects have small brains. No one would seriously suggest that a smaller computer was an inferior computer merely because of its size, he says, yet that still seems to happen with brains. He argues that it is time to get beyond size and numbers of neurons and start looking at neural circuitry. Cognitive abilities such as numerosity, attention and categorisation - all found in insects - seem to require only small numbers of neurons. So it may turn out that brain size has less to do with cognitive capacity and behavioural repertoire than we have assumed (*Current Biology*, DOI: 10.1016/j.cub.2009.08.023). "We've gone as far as we can with size," he says.

NIC BOTHMA/EPA/CORBIS

Size isn't everything. Bees have been shown to learn more quickly than human infants

several lineages, including mouse lemurs, marmosets, mangabeys and possibly also humans – as suggested by the discovery in 2003 of Flores man, aka the "hobbit", whose brain was around one-third the size of ours (*BMC Biology*, DOI: 10.1186/1741-7007-8-9).

Mundy's analysis also suggests that we should be wary of invoking the ratio of brain to body mass as evidence of our cerebral superiority. When his team evaluated how body size evolved in primates, they found no overall trend. In some primates, such as gibbons and colobus monkeys, as their brains grew bigger, their bodies got smaller. In others, like the gorillas, brain mass grew but body mass grew a lot more. The team conclude that primate brains and bodies evolved in response to different selection pressures, so that their sizes are not necessarily correlated.

Herculano-Houzel, who has recently used her neuron counting technique to analyse orang-utan and gorilla brains, agrees. She found that they conform to the same neuronal scaling rules found in other primates, with a high density of neurons per volume and no increase in neuron size with body size. Where the great apes do differ from other primates, however, is that their bodies are bigger than you would expect for their brain size. Body size and brain size don't always evolve in lock-step, she concludes. So although a gorilla weighing about the same as a human has a brain just one-third of the size, it is actually the body size of the gorilla rather than the brain size of the human which is the outlier. "We've been emphasising the wrong thing."

Exactly what is the right thing to emphasise is a matter of debate. Over the years scientists have come up with numerous contenders in their attempts to explain human cognitive superiority. Some point to the neocortex, which in evolutionary terms is the newest part of the brain and is involved in higher functions including conscious thought. Studies of the neuroanatomy of living primates show that the human neocortex is significantly larger than expected for a primate of our brain size (*Journal of Human Evolution*, vol 37, p 191). Another contender is the cerebellum. A study that looked at 41 monkeys, 42 apes and 14 humans found that apes and humans show a striking increase in the size of the lateral cerebellum, a region implicated in cognitive tasks (*Journal of Human Evolution*, vol 44, p 401).

Then there are the glial cells. For years considered mere support cells in the brain, glia have recently been recognised for their important role in transmitting signals (*Nature Reviews Neuroscience*, vol 6, p 626). A study of Einstein's brain revealed that he had a higher glia-to-neuron ratio than the dead males doctors used as controls. This fits with a growing body of work suggesting that this ratio is associated with intelligence differences between species (*Nature Neuroscience*, vol 10, p 331). However, it is unclear how glial cells influence intelligence. What's more, despite the widely held assumption that humans have a glia-to-neuron ratio of 10:1, Herculano-Houzel's study found it to be more like 1:1.

All these explanations of human intelligence still assume that more is better, but that hegemony is now being questioned. Studies with insects, for example, suggest that the way a brain is wired up could be the key to intelligence (see "Well connected", left).

At least Herculano-Houzel's work should finally dispel the simplistic notion that size is all important. The number of neurons in a brain almost certainly matters more than mere brain size – which shouldn't be considered a proxy for neuron endowment any more, she says. ■

Alison Motluk is a science writer and broadcaster based in Toronto, Canada