

Rationally Speaking #157: Dr. Herculano-Houzel on “What made the human brain special?”

- Julia: Welcome to Rationally Speaking, the podcast where we explore the borderlands between reason and nonsense. I'm your host, Julia Galef and I'm pleased to introduce this episode's guest, Suzana Herculano-Houzel. She's a professor of biomedical science at the Federal University of Rio De Janeiro in Brazil. Soon, in a month or so will be professor and biological sciences at Vanderbilt University.
- She's written eight books now on science for the general public. And we're going to be talking about her most recent book and her first book in the English language, *The Human Advantage*, which addresses the question, it covers her own original research, and the question she's focused on is what makes humans special? Essentially, what is it about the human brain relative to the brains of other species that gives us the huge cognitive advantage, the many cognitive abilities we have that other animals don't have. What is it about our brain that gives us that. Suzanna welcome to the show.
- Herculano-Houzel: Thanks Julia, it's a pleasure to speak to you.
- Julia: So I thought we could start by putting this question in a historical context. I know generations of scientists, of people throughout the ages, have wondered what it is that makes humans special. What are some of the previous approaches people have taken to this question? What are some of the previous theories people have had about what makes humans special?
- Herculano-Houzel: Well I think the original and simplest idea was ever since people realized that it is the brain that produces all of our mental capacities, that whoever had the biggest brain should also have the most abilities.
- Julia: Right.
- Herculano-Houzel: Which kind of makes sense because brains are made of neurons. Neurons are the units that process information. So in theory it sounds intuitive enough that whoever has the biggest brain should also have the most neurons and cognitive ability should just come along with that.
- Julia: Right. Like having bigger muscles makes you stronger.
- Herculano-Houzel: Yes exactly. But the problem was that it was quickly realized, I believe by the end of the 19th century, that humans do not have the largest brain around. An elephant brain, which I've held in my hands, is about the size of my forearm. That's three times as big as a human brain.
- Many dolphins and whales actually have brains that are much larger than the human brain and even larger than an elephant brain. Once you realize that we pale in comparison to those animals in terms of brain size, it seems pretty obvious that either all brains are not made the same way, but that took a long time for, to come up. Or else you just think it's not absolute brain size, maybe it's something else.

Maybe the human brain is special in its relative size compared to our body because larger animals usually have larger brains, but gorillas have larger bodies than we do, up to three times as large as a human body. So you would expect gorillas to have bigger brains to go along with bigger bodies and yet it's the other way around. The human brain is about three times as large as a gorilla brain.

That's where this idea came from that the human brain, even though it is not the largest brain around, it still is the largest compared to what you would expect the human brain to be for the size of our body.

Julia: Right Right. I can see intuitively how that hypothesis seemed like a good corrective to the original hypothesis that it was just about absolute size. Although I still don't quite grasp how that was supposed to work.

Herculano-Houzel: I know. So the idea is that larger bodies require larger amounts of brain to take care of that body. If you have enough brain to take care of that body and an extra amount of brain, then you're better off than other animals that have just enough. See?

Julia: I see.

Herculano-Houzel: That's the original idea. I do not think that's right for a number of reasons, beginning with the fact that the number of neurons that actually are directly related to taking care of the body is amazingly small. That does not increase very rapidly as the size of the body of an animal increases.

So I've come to think that it's really just the absolute number of neurons that you have in your cerebral cortex. Especially in those parts of cerebral cortex that go beyond just receiving sensory information and organizing muscle movement, lets say. I think that that's what really matters regardless of the size of the body. But I'm getting ahead of myself.

Julia: Right.

Herculano-Houzel: That was the idea. That if you have extra brain compared to what you would, in principle, need to have to operate your body, that would give you an advantage. And because that ratio, that extra amount of brain, is by far the largest in relative terms for humans, that seemed to single us out. People were very happy with that answer for actually a couple of decades.

On top of that we've recently had an explosion in numbers of studies on comparing genes across humans and chimpanzees and macaques, that's the usual comparison, to see what is different about the human brain. Of course you find that a number of genes are different.

The issue to me is that, well, wouldn't you expect to find a number of genes to be different anyway. Because after all if you look at a human and at a chimpanzee and I don't tell you which is which, you're not going to have any doubts. That's because there are a number of genetic differences across the species.

Julia: That doesn't-

Herculano-Houzel: Right. If so you have these obvious differences on the outside I wouldn't expect anything less than there to be differences on the inside as well.

Julia: Right right. Yeah, I think there's a tendency in neuroscience and in genetics, at least in the popular understanding in those fields, to think that you've sort of resolved a question just by showing, "Look, there are differences between activity in two regions of the brain," or "Look, there are differences in the genetics" and think, well that's the explanation for the question we were interested in. But often that doesn't really get you very far.

Herculano-Houzel: Exactly. I think the answer necessarily will be there are a number of differences. Not just this or that. But in terms of our cognitive capabilities -- or abilities, really. And I think there's an important difference between those two words. Capacity or capability for me is what you're biologically endowed with, what you're literally physically capable of doing and what you turn those capabilities into, so what you actually do, and that depends a lot on your effort and your opportunities, those are your abilities.

Julia: I just want to explore what we mean by cognitive capacities or abilities a little bit.

When we're making these cross-species comparisons it seems pretty difficult to have a way to measure ability that is meaningful across species. For humans, one way to measure people's cognitive abilities is with an IQ test. But you can't really give that same IQ test to a bird and to a chimpanzee and have a meaningful comparison there, right? How would neuroscientists interested in this question measure something like that?

Herculano-Houzel: You're absolutely right. That is a huge problem. Right now, the best that we can work with is, well, besides this general intuition that however you define or measure capabilities or abilities, we must come out on top because well we're the species studying other species and not the other way around. At least we don't think so.

Julia: Right. Though I'm sure that some undergraduates somewhere want to say that, no, humans don't come out on top. The species that come out on top are the ones that aren't killing each other and ruining their planet. That's the *true* measure of cognitive ability!

Herculano-Houzel: You know, I've been that undergraduate -- although not based on that argument, that it must be some other species that's not out there killing each other. I think that's one of the signs of dominance, exactly, that you're cognitively capable enough to enforce your dominance over other individuals or other species.

Anyway, defining and measuring abilities or capabilities is a huge problem. I don't think we have a proper way of doing that yet. Essentially there have been two approaches. One is choosing one or two tasks that are general enough and simple enough they can be applied to widely different species. Sticking to those tasks and

trying to compare those species, that has been done. Although some of the people I talk to have criticisms to that like how easy is it? How valid is it to apply it to different species?

Another approach is to be on the opposite, on the contrary, to be as general and as inclusive as possible and add a mixed bag of cognitive tests, on memory and learning, and self control and whatnot. But then the problem is that you're necessarily restricted to similar species. That is an approach that has been used for nonhuman primates. In that case what they found was that the best correlate with this general cognitive index across nonhuman primates is simply the size of your brain or the size of your cerebral cortex, because you can't really dissociate one thing from the other.

But anyway the important part is it's not that relative measure of how large your brain is relative to how large it should be for the size of your body.

Julia: Which is interesting, because then that finding wouldn't really hold up across very different species. It only has validity within a cluster of similar species.

Herculano-Houzel: Exactly, which is, by the way, the very observation that got me started thinking that all brains must not be made the same way. At least not in terms of how many neurons go into brains of different or similar sizes. Because, here are my favorite comparisons, if you take a chimpanzee brain and a cow brain, they both have a similar size. It's about 400 grams. Which by the way is a very respectable brain size.

If those two brains were made the same way, you would expect them to be made of similar numbers of neurons. And if neurons are the basic information processing units of the brain then those two brains should have similar cognitive capabilities.

And yet, like I said, one belongs to a cow and the other belongs to a chimpanzee. This is where, like you were just asking, we should be concerned about what we really know about the cognitive abilities or capabilities of cows and chimpanzees. Maybe cows have this really really rich internal mental life while they're just grazing. They're doing deep philosophy. They're so good about it that they don't let us in on it.

This is where ... This is the difference between just being and observer in the world and actually doing science. We can look at a cow and at a chimpanzee and think, well, I'll stick with a chimpanzee. I think that a chimpanzee can do much more interesting and flexible and complex things than a cow can.

But that's just your impression. Until you actually get down to collecting facts systematically and comparing them systematically and objectively, that's really just an intuition.

The problem is right now that still is the best that we can do. So we're badly in need of direct systematic way of comparing cognitive capabilities across species.

Julia: I see. The way that we got here was we were talking about ways that people in

previous decades or previous generations of science had attempted to answer this question about the human advantage. Before we move on to talk about how you approached it, I just want to check and make sure, does that roughly bring us up to speed? Were there more modern scientists that had another theory before you came along, that's worth mentioning?

Herculano-Houzel: It was essentially this combination of, the human brain is larger than it should be for the size of our body; we also have different genes that are expressing neurons and in synapses. Maybe the human brain has a different connectivity, a different pattern of connectivity, which isn't really the case. You would have to get down to details to find something that is different about the connectivity of the human brain. Even that, I would still argue, that is just a byproduct of having more neurons in the cerebral cortex. Although that's still up for grabs.

The other thing that seemed special about the human brain is that for its size, for its relative size, it costs way too much energy. The human brain represents about 2% of the mass of your whole body. So you would initially expect it to cost about 2% of the energy that your body uses. But it costs 10 times as much. It's about 20% to 25% of all the energetic cost of your whole body is your brain alone.

Julia: What is that ratio like in other species? Is it roughly proportional to body size?

Herculano-Houzel: It's more than proportional. That was known already that the brain, gram by gram, the brain is more expensive than the rest of your body. But at best it costs 8% to 10% of the total energy costs of the body in other species. So we did seem to be an outlier in that regard.

Julia: Interesting. Okay. I think that pretty well sets us up with the mystery that you are trying to solve, and previous stabs at it. Do you want to tell our listeners what your innovation was that helped us get some traction?

Herculano-Houzel: Sure. I think it started with just thinking that there was something fishy about this story that all brains are made the same way. Because of comparisons like I just mentioned across cows and chimpanzees or birds and other species. Birds have very small brains and yet they're capable of doing things that monkeys are also capable of doing with brains ... Monkey brains are typically what, 5 to 10 times bigger than bird brains.

I realized that we actually did not know how many neurons different brains were made of and how that compared across species. Basic questions like how many neurons does the human brain actually have? Does it have, do we have fewer neurons than larger brains like an elephant brain or a whale brain? I realized that it was still possible that maybe the simplest answer for what is it that sets humans apart in their cognitive capabilities. What if it's simply a large absolute number of neurons -- in the brain as a whole, or maybe in the cerebral cortex in particular -- that nobody else has?

Julia: Why had we not already -- I would imagine just naively, that neuroscientists would have jumped on the project of trying to count neurons in the human brain. Was

there a block to that before?

Herculano-Houzel: That was [surprising] to me, and maybe I guess this is one of the advantages of not belonging to this field. When I got started I trained as a neurophysiologist. I trained and I got my PHD recording neurons responding to visual stimuli in animals.

I became interested in this issue of what brains are made of and how they compare when I started at the science museum with the general public. I realized that 60% of college educated people in Brazil and in Rio accepted the notion that they only used 10% of their brain. Which is absolutely not true. You use your entire brain the whole time. You just use it in different ways and you can learn to use it more efficiently or better and solve problems more rapidly and so on.

One of the possibilities behind that 10% myth was that, well you open any textbook, and you most likely see that the human brain is made of 100 billion neurons and ten times more glial cells. So you see that neurons come out as roughly 10% of your brain cells.

I started looking around for that number and it turned out that it didn't exist. Like you did, I was surprised. I just expected this to be one of the most basic issues in neuroscience. If you want to figure out more complex, intricate things about brains, you would, I thought you would, start by figuring out what different brains were made of and what are the rules, let's say, for putting brains together.

Apparently there was a simple reason why we didn't know those number, not even for the human brain. Which was a lack of a technique, of a method really, that would allow you to estimate accurately numbers of neurons in the whole brain of different species. The major difficulty is the method available then, which relied on very very precise intricate systematic microscopy. And it had the problem that distribution of neurons in the brain is highly heterogeneous.

You can have a low density of neurons right here, then you move two millimeters to the left and you find a density that's five times bigger in a different structure. There was a technical difficulty behind that, and on top of that there seemed to be this assumption that, well, all brains are made the same way so why bother? Whoever has a bigger brain should also have more neurons. End of question. Next question.

Julia: So you could just extrapolate up from smaller brains?

Herculano-Houzel: That was the idea that ... Not even that you would have numbers because the numbers didn't exist. But that there was a consensus that larger brains are made of bigger neurons. That's because you see the density of neurons decrease across the species that had been compared in the past. You know that larger brains have bigger neurons and people would just assume that larger brains also have more neurons.

People in the field seem to be pretty content with that notion that, well, you take two brains; if they have similar size, they have similar numbers of neurons. A bird brain is smaller so it must have fewer neurons. Whoever has the biggest brain wins, has the most neurons.

I had to come up with a different way to count neurons. That's what I called brain soup.

Julia: Brain soup. Delicious. Tell me what that is. What's your recipe for brain soup?

Herculano-Houzel: My students tell me I've killed apple juice for them because that's pretty much what it looks like.

Julia: Oh no.

Herculano-Houzel: You take fixed tissue. It can be a whole brain, it can be any part of the brain that you can dissect, that you can cut apart from the others and study it separately. So you take that chunk of fixed tissue, and by fixation I mean that the tissue has soaked in formaldehyde, paraformaldehyde. That makes the membranes of the cell nuclei very very sturdy and resistant to detergents and mechanical friction.

You take that fixed tissue and you really dissolve it in a detergent solution. To do that we use a glass -- it's like a mortar and pestle, that's pretty much what it is but in the shape of a tube. You start with your chunk of tissue and in 10 to 20 minutes depending on how large the chunk of tissue is, you've turned it completely into soup. That soup now consists of all the nuclei of the cells that once composed the tissue, except that now they're freed of the cell membranes, so you have these nuclei just floating in a suspension.

The beauty of having the nuclei now floating freely in a suspension is that, first you can round up the volume of the suspension, so you know exactly how much volume you have. Once you've done that you can just slosh it around, just agitate it, and by doing that you're making the nuclei become distributed evenly in the suspension.

Once you have that you can just take 4 or 5 tiny little samples to the microscope and you can actually count, with your eyes, you can count how many nuclei you see per given volume of the tissue. Because of the suspension and because you know what the total volume of the suspension was, it's just a simple extrapolation -- and you know what was the total number of nuclei and therefore the total number of cells that you had in the tissue.

It's pretty fast. It's accurate. That gives you the total number of cells. Now by using an antibody that, its a protein, a molecule that binds specifically to the nuclei of neurons, it makes them red. You go back to the microscope and now you count what fraction of all the nuclei actually are neurons. That's another couple of hours and after ten more minutes at the microscope you now also have the total number of neurons that were in that structure that you started with.

Julia: You can get the same count for glial cells and things like that?

Herculano-Houzel: The glial cells for now, what we work with is just by subtraction. We take that number of neurons from the total number of cells that you had in the tissue. That is technically the number of non neuronal cells in the tissue or other cells in the tissue. But because the only other non neuronal cells that are not glial are the cells that

make up the capillaries in the brain, and because the volume of capillaries is very very small, its around 2% of the volume of the tissue, we assume that the vast majority of the non neuronal cells in the tissue are actually glial cells. That's the number we work with for now.

Julia: What did you find? How close was the total number of neurons in a human brain and glial cells to what our best guess had been?

Herculano-Houzel: The total number of neurons, what you find in textbooks, is 100 billion neurons which I came to realize was an order of magnitude estimate. As an order of magnitude estimate it was really good. We found, on average, 86 billion neurons. I would like to point out those are male Brazilian brains of people aged 50 to 70 years.

Julia: That's very meticulous of you! Because most psychology studies just say it's found that "people" react such and such a way. They don't say it's found that "18 to 22 year old psychology students at ivy league universities in the northeast" react this way. So good job.

Herculano-Houzel: Yeah thanks. I'm in the business of numbers and reporting what brains are made of and how I think that's important. So we have to be careful about what it is that we're comparing.

Julia: Excellent.

Herculano-Houzel: For a number of purposes that is of course not enough. We would like to know how that compares to women. Younger and older. One of my main interests right now is actually figuring out how much variation you find across individuals.

We know already in mice, these again were male mice exclusively to avoid for now the problem of sex differences. We know that in mice of the same age, those animals with the bigger brains are not necessarily the ones with the most neurons.

Julia: Interesting.

Herculano-Houzel: Across individuals there is no correlation between the size of your brain or the size of the brain structure and how many neurons that structure has. We're trying to find out, of course, whether that is also true for humans. We know that it's also true for other species. But we need to look at humans specifically.

The important thing is that for the purposes of what we were doing back then, which was comparing not individuals but comparing species, this average of 86 billion neurons give or take a few for Brazilian males aged 50 to 70 was good enough that we could compare to other species. Other primates, other non-primates.

The number of neurons was fairly close to that order of magnitude estimate. Though some people try to tell me, "86, 100 billion -- who cares? It's all the same." I'm like, no it's not. The difference is 14 billion neurons and that is more than an entire

baboon brain. Baboon brains are pretty big.

The important thing about that estimate of 86 billion neurons and not 100 is that it puts us squarely with other primate brains.

Julia: In terms of number of neurons.

Herculano-Houzel: In terms of the relationship between the size of the brain and how many neurons it has, and actually also in terms of the relationship between the size of the body and how many neurons the brain that goes inside that body has.

That is true provided that you are not looking at great apes. Which we couldn't do back then, simply because we didn't have tissue from great apes. That's what got me started thinking that maybe we've got it all backwards this whole time. Maybe it's not the human brain that is an oddity. Maybe it is not humans that are an evolutionary exception or oddity. Maybe it's the great apes that for whatever reason cannot have as large a brain as you would expect for their body size.

That is a story that we pursued and that I tell in the book, because it does turn out that now that we do have the data, gorilla and orangutan brains, they seem to be made in exactly the same way as other primate brains including human brains are made. With the very same relationship between the size of the brain and the number of neurons that applies to everyone else.

Where they do fall out of the curve, and by a lot, is in this relationship between how many neurons you find in their brain and the size of their bodies. Indeed, if you compare, if you use every other primate as a basis for comparison, humans fall right where you would expect the generic primate to fall in terms of how many neurons in the brain for the size of their body. You find that it is gorillas and orangutans that are, lets say, missing neurons for the size of the body they have. Or else they have a much larger body for the number of neurons that they have in the brain, see?

Julia: Why is the size of the body adjustment relevant here? Given that as you mentioned earlier most of the brain isn't devoted to controlling the body. Why are we adjusting for that?

Herculano-Houzel: To begin with because you have to keep going with the existing arguments in the literature. If I want to make the point that I think things are different and actually the size of your body is not all that relevant, not in terms of how many neurons you need to operate, then I actually have to do the proper comparison and show that well look, humans are not the species that falls out of the curve, it's great apes.

Really the reason I think that it's this relationship between, or this oddity in the relationship between number of brain neurons and the size of the body is that once you realize that all of this costs a lot of energy, and actually adding more neurons to the brain costs a lot more energy.

That's when I started to be suspicious that maybe the reason why great apes are the odd ones out, that they don't have as many neurons as you would expect for the size

of their body, is that maybe they're limited by their diet. They're constrained in such a way that they can either afford a very large body or a very large number of neurons, but they can't do both.

That does seem to be the case. That's what we found out when we did the math comparing how much energy different primate species get from their natural diet and on the other side of the scale how much energy their bodies cost based on how large they are, and how much energy their brains cost based on how many neurons they have.

Julia: So would it be correct to say the takeaway here is that human cognitive abilities are no greater than you would expect if you just took a primate brain, and didn't change its structure or the algorithms it was using, but just added more neurons to it?

Herculano-Houzel: That's exactly what I think.

Julia: Okay interesting.

Herculano-Houzel: The key question becomes, well, there's actually a number of questions. One of them is, of course, how come humans are the only primate species that managed to have that many neurons in the brain? We could come back to that.

The other one still is, well what about other animals? What about an elephant? Do we still have more neurons than an elephant? The answer is yes and no. If you compare the whole human brain, our brain is one third the size of an elephant brain, and it does have about one third the neurons that an elephant brain has.

But, and this is a huge huge but, 98% of the neurons in an elephant brain are found in the cerebellum. Which is, it's really not just a sensory motor structure like people say in textbooks, but it probably does have a lot to do with a structure that elephants and elephants alone have that is enormously sensory and has a lot of motor precision and that's the trunk.

You've got to realize that the trunk of an elephant is pure muscle and sensory receptors. It can do very very precise movement with infinite degrees of freedom because it has no joints. There's no articulation inside the trunk.

When you compare the cerebral cortex alone -- and that's the part of the brain that we think is where the, let's say, the higher cognitive processing happens; not only sensory motor integration but also pattern finding and planning for the future and relating to others. Those are all functions of the cerebral cortex. Once you compare the cerebral cortex alone, what you find is that even though the human cerebral cortex is only half as large as an elephant cerebral cortex, the human cerebral cortex does have three times as many neurons as the elephant cerebral cortex.

Actually, we do seem to have the most neurons in the cerebral cortex of any species on earth. That includes whales as well, even the largest ones which by our estimates only have as many neurons as you find in the elephant cerebral cortex.

So we have 16 billion neurons on average in the cerebral cortex. Second place is gorilla and orangutan. Chimpanzees have between 6 and 7 billion. Then you have the elephant with 5.6. Whales probably have between 3 and 4, maybe at best 5 billion. Everybody else, even the other animals that have large brains like giraffes, they have fewer than 1 billion neurons in the cerebral cortex.

The reason for the difference between humans and everybody else is that we have a primate typical brain, and non-primate species do have fewer neurons in the same brain volume, or in the same volume of the cortex. The reason is that when you are not a primate, as your brain gains neurons, neurons do indeed become larger like people had suspected in the literature.

The difference is that primates don't follow that rule. When primates diverge from other species in evolution, the rules for adding neurons to the brain changed -- and now if you are a primate you gain more neurons, but the average neuron does not become any bigger.

Julia: Which allows you to fit more neurons into the same mass.

Herculano-Houzel: Exactly. I like to think that it allows your brain to increase in size very rapidly as you gain more neurons.

Julia: Right.

Herculano-Houzel: When you compare a primate and a non-primate, when you compare a primate brain with a non-primate brain of a similar size, what you find is that the primate brain always has more neurons, especially in the cerebral cortex, than the non-primate brain. The larger the size of the brain, the larger this gap will be. Primates always have more neurons than a non-primate which is what I call the primate advantage.

Julia: Got it. So the human advantage basically consists of, first, the primate advantage -- being able to fit in more neurons without growing the brain to an unwieldy size -- then on top of that, just adding more neurons, which other primates didn't do essentially. Is that right?

Herculano-Houzel: Yeah, exactly. Which brings us back to that first question of: why we humans? Why don't chimpanzees or gorillas or orangutans also have more neurons, especially gorillas, given that they do have the larger bodies that you would expect to come with more neurons?

That's where we started doing the math about how much energy these different species have available to pay for a certain body mass and a certain number of neurons.

That's when we realize gorillas have pretty much hit the energetic wall. They cannot feed for more than 8 hours per day which is how much time they spend foraging, which means actively looking for food and also eating.

They would need an extra 180 kilocalories if they were to have as many neurons as you would expect them to have for the size of the body that they have. It doesn't sound like a lot. You eat an apple and an apple, two apples would take care of 180 calories.

But the problem is, we think that it's not a lot because we have refrigerators in our homes now. If the fridge goes empty you just go down the street to your grocery store and you can get all the calories you need again.

Julia: Right, and we've bred food to be way more calorically dense than it used to be, right?

Herculano-Houzel: Exactly. I think that's the key thing about industrialized foods that get all the bad rap. But actually if you think that the original problem that our species solved was how to get enough calories, we're amazing. We have this amazing possibility that no other species has, that eating the 2,000 calories that we need for the whole day in just a single 15 minutes sitting at your favorite junk food restaurant.

Julia: I love how you frame that as an achievement, as a grand achievement.

Herculano-Houzel: Well because it is. Just think that a gorilla needs to spend 8 hours per day to get the circa 3,000 calories that it needs. If by the same math, if we still ate like other primates do in the wild, we would have to spend over 9 hours per day looking for food and eating. That's how much time our ancestors would have had to spend per day just looking for food and eating food, and repeat all day long, just to afford the body that they had, and this many neurons as we have in the brain today.

Once you realize that, well just to be clear, if you had to spend 9 1/2 hours per day foraging, looking for food -- forget school, forget podcasts about how the human brain compares to any other brain, we would not be doing any of this. We would still be out there just looking for food every single hour of the day.

Julia: There's something I don't understand here. It feels, naively, like there's kind of a chicken and egg problem. Where you have to be above a certain level of cognitive ability in order to come up with the innovations that allow you to make it easier to get calories every day.

Herculano-Houzel: Exactly.

Julia: But you also have to have enough calories to grow your brain, or your number of neurons large enough, to be smart enough to know how to do that.

Herculano-Houzel: Yep, exactly.

Julia: What's the answer?

Herculano-Houzel: This is where a little bit of knowledge about the human evolutionary history helped solve the problem. Because the thing is, before our brains started to really increase rapidly in number of neurons, which is the feature that most sets us apart from

everybody else, our ancestors not only had enough neurons already to use tools, which is something that chimpanzees do, gorillas and orangutans do, even some birds also do. They first, our ancestors became bipedal.

And there's a lot that comes with becoming bipedal. It's not simply just having free limbs to carry stuff, to carry your tools. Much more than that, once you become bipedal, walking costs much less energy.

Do you remember seeing chimpanzees walk? They have that funky sideways gait with their knees splayed sideways. Chimpanzees are still quadrupeds. It costs them a lot of energy to walk. A bipedal human ancestor would have used 4 times less energy than a chimpanzee to walk around which means that you can actually extend your range of foraging. That already gave them an advantage in terms of being able to find enough calories for the day. Just because you can go farther in the day because it's easier to walk, and walking costs less calories.

Maybe that put them at a small advantage already compared to non-bipedal, every other primate. On top of that, about 3 million years ago our ancestors also learned to not just use natural objects as tools, but actually to make their own tools. This is where technology comes in and plays a huge role in our biological evolution also, because making tools is actually creating a technology.

You learn, you create this method of using a naturally available object to shape another naturally available object into say a stone knife. Now you have in your hands something that nobody else does, and it's a tool that you can use to kill animals, carve meat, crush roots.

All these are things that you can do that start processing the food that you eat before you put it inside of your mouth. That goes by the name of cooking. Even before fire. Even before you learn to use fire as a tool to modify even further the food that you eat, see?

What starts setting us apart from other apes is this combination of biological change which is bipedality, with this technology that other primates don't have. I think it's really interesting how this first, this initially very simple technology, the making of your own tools, can actually feed back into your biology. Because it allows you to get more calories and then this whole thing just spirals up and very rapidly.

You could even say out of control, but not really -- because the more technologies you have, the better you can modify your food. The more calories you get and therefore the more neurons you can afford in your cerebral cortex, which gives you more capabilities.

This is the important part. This is where it's important to separate between capabilities and abilities. As you become, as human ancestors and human ancestors alone become capable of getting more calories, having a larger brain with more neurons is no longer a liability. Much to the contrary, it now gives you this advantage of having more neurons to work with, which in principle gives you a cognitive advantage of having more cognitive capabilities.

Now, as you use those capabilities to solve problems, which by the way is where it comes in really handy that you now have this cool technology of preprocessing the food before you eat, because maybe the biggest advantage that comes from cooking your food is that it takes much less time to get all the calories that you need. Just try eating a raw carrot. It takes forever. It tastes horrible, and it takes forever. As soon as you cook that carrot, and you don't need to do anything fancy to it, just toss it in the oven. Just hold it over a fire. Just roast it. It not only becomes tasty but you can now eat the whole thing in just a couple of minutes.

The really important thing about that is now you have free time to do much more interesting and challenging things with your capabilities that your neurons afforded you, see? Having more problems to solve actually helps you turn those biological capabilities into actual abilities. Then if you have enough neurons to allow you to pass those abilities on to the next generation through teaching, then you really close the circle. You're all set. You're ready to just spiral up and have those, that larger number of neurons that are now affordable, actually translate into more cognitive abilities that you can pass on.

Julia: Well, we are now over time so I'm going to wrap up this section of the podcast. But I think this has been a great walk through of the mystery, as it has existed, about the human advantage; and what explanations previous generations have come up with, and why those have been unsatisfactory; then the technological innovation that allowed you to approach the question from a different angle, and what the implications of your answer have been. So it's been great. Thank you so much.

Okay, so now we'll move on to the Rationally Speaking pick.

[interlude]

Welcome back. Every episode we invite our guest to introduce the Rationally Speaking pick of the episode. It's a book or a blog or a movie or something that has influenced their thinking in some interesting way. So Suzana, what's your pick for this episode?

Herculano-Houzel: I pick *Catching Fire* by Richard Wrangham. It's a book that enormously influenced my work. And that's where I first read about this idea that cooking -- in his the way he tells it, he focuses on cooking with fire, but it doesn't matter -- the important thing is this idea that transforming your food actually was really the watershed event in human evolution. Richard Wrangham was the scientist who first proposed that the enormous and fast increase in brain size in human evolution actually started with the advent of cooking.

This book is a delight to read and I think anybody from any background will be able to read it and also enjoy it a lot.

Julia: Excellent. Well, we will link both to your book *The Human Advantage* and also to your pick on the Rationally Speaking website, and once again thank you so much. It's been wonderful having you as a guest.

Herculano-
Houzel: Thank you Julia, it was a pleasure to talk to you.

Julia: Before we close I just want to remind all of our listeners to get your tickets for Necss. That's the northeast conference on science and skepticism taking place this May 12th through 15th in New York City. Keynote speaker this year is the always excellent Richard Weisman. Other featured speakers include Bill Nye the Science Guy and the entire cast of The Skeptics Guide to the Universe. Of course, I'll be there taping a live show. Get your tickets now at Necss.org. That's n-e-c-s-s dot org. Hope to see you there. And now, this concludes another episode of Rationally Speaking. Join us next time for more explorations on the borderlands between reason and nonsense.