Neurobiology

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Lecture 1.3: An evolutionary perspective

In the last few videos, we have looked at the historical perspective of how we have learned about the human brain. In this video, we are going to look at the evolutionary perspective. How the human brain compares to other animals. Is it similar or is it unique in some very special ways? And in particular, what might account for the higher intelligence in humans? Now, I am not going to define what intelligence is because that is a very controversial topic and I am sure there are people who would argue that humans are as intelligent as other species and other species are intelligent in their own ways as required by their ecological requirements. But I think generally speaking, most people would agree that humans have higher ability to solve problems, solve new problems. So what might account for this ability? What do you think might be unique about human brains that gives humans this ability to solve problems better than others? Okay, so which aspects of the brain determine intelligence? Could it be the size of the brain? Well, that does not look like a very good measure because say larger animals would have larger brains.

So cows would have larger brains than cats. But that would not mean that cows are more intelligent than cats. What about the number of neurons? That does seem like a better measure. So let us see how many neurons there are in different species.

Here is a table showing the number of neurons for a few common species. On top here is C. Elegans which is a small worm and has about 300 neurons. Then after that, insects, say fruit flies have about 100,000 neurons and mosquitoes have a similar number of neurons. Some other insects like honey bees or locusts may have about a million neurons.

Then mice have about 71 million neurons. Cats have an order of magnitude higher about 760 million neurons. And humans have almost 100 times more, 86 billion. So it does seem like humans have a larger number of neurons and these numbers do seem to correspond roughly to how we would classify this species on the ladder of intelligence, at least in common terms. So just an aside, how do you think these numbers of neurons could have been estimated? You know, you might like one option could be to put the brain under a microscope and count the number of neurons.

But as you have seen before, the brain is too dense and these numbers are too large to do this kind of counting while looking at a brain under a microscope. So what could be done to solve this problem? So what was done actually is that scientists took these brains and then you could put them in a large container in some solution and basically dissolve the brain so that all the cells become loose. You break open the cell membrane so that the nuclei can come out and then you homogenize this whole thing. And then you could count, you could take a small sample and count the number of nuclei in that sample. And then you can extrapolate from that sample to the overall volume and get a rough estimate of the total number of neurons.

And this also takes care of the problem where like if you were taking a small part of the brain and then extrapolating then you have this risk that the number of neurons in that part may not be representative. That part may have higher density or lower density of neurons and other parts. But once you homogenize, then you take care of that variability and you can get an overall estimate of the numbers. Okay, so coming back to the correlation between the number of neurons and intelligence, it does seem like a reasonable correlation. But do you think humans have the largest number of neurons? Well, it turns out elephants have more neurons than humans.

They actually have about 256 billion neurons. So, the number of neurons although it does seem to have a positive correlation, it is not a perfect correlation. But there is one aspect in which humans beat elephants and that is the number of neurons in the cerebrum. So, most of these neurons in the elephants are actually located in the cerebellum, which we know is an area that is involved in the control of muscles, probably because elephants have a lot more muscles that need to be controlled. But the cerebrum that is more involved in problem solving, humans have more neurons, about 20 billion neurons compared to 6 billion neurons in elephants.

But even in this respect, humans are not at the first position. There are actually whales that have about 36 billion neurons in cerebrum, which is more than the humans. So, then in what respect are humans better than other species? So, you might be thinking that these animals, elephants or whales, these are much bigger animals than humans. So, perhaps the ratio of the brain to the rest of the body that determines how intelligent the species is going to be. But if we look at the brain to body ratio, brain to body mass ratio in different species, again it turns out that there are other species that, some species that beat humans.

So, there are insects and some vertebrates that have the body, brain to body ratio of 1 is to 10, while for us it is about 1 is to 40. So, our brain, as I mentioned in a previous video, is about 1.5 kgs and considering a body weight of about 60-70 kgs, the ratio is about 1 is to 40. So, it is not clear if there is any one single parameter in which humans beat all the other species. I encourage you to go online and search if you can find something more.

But it may also be that the intelligence is not simply determined by one quantity, but it is more about how many neurons there are and how those are connected in what manner that might determine the intelligence. On the screen here, you can see two skulls and within those you can see the schematics of brains of the corresponding animals. On the left here is the human skull and the human brain. Can you guess which animal is on the right? See if you can figure it out. So, this is actually the chimpanzee brain.

Now, looking at these pictures, what can we infer about the human brain and the chimpanzee brain? One thing that is pretty obvious is that the human brain is larger in size. That is quite clear. But what else can you see from these images? So, I guess the other thing you could also notice is that the shape of these brains look quite similar in the human brain and the chimp brain. And if you think about it, why is it that the human brain has the same shape as a chimp brain? Why are they not completely different or independent? Why did they have to be similar? Well, they are similar because they are linked by evolution. It is not that the human brain was designed or it came about independently.

It has evolved from the brains of simpler organisms, just like other body organs. And this is the reason why we can use model organisms in biology to learn various things about the human body and about the human brain. In fact, if we look further than chimpanzees, if we go further back in the evolutionary history, then we share common ancestor with monkeys and even the monkey brain looks quite similar in shape as the human brain. Although you can see that the human brain is bigger in size and chimpanzee brain is somewhere in between. The similarities can be seen even if you take cross sections of the brain as shown here.

This is a cross section of the human brain, chimpanzee brain and monkey brain. And although there are some subtle differences, but probably you can see the same kind of organization because all these brains are linked by evolution. Now, there is a very famous quotation in biology by Dobzhansky, which says that nothing in biology makes sense except in the light of evolution. And this is also true in the case of understanding the brains. We can learn a lot by looking at the evolutionary history of the brain and by comparing the brains of different animals, we can try to understand the functional roles of different features of the brain.

Let's think about the difference between humans and monkeys in some more detail. Let's also consider the differences between our behaviors. In what aspects humans and monkeys are similar and in what aspects we are different. So of course, in terms of basic bodily functions like breathing or digestion, we are quite similar. And even in terms of our basic senses, the ability to see or smell or listen, we are probably not that different.

But the main differences come in terms of the cognitive abilities or ability to use language or ability to solve problems. That's where humans are quite different from monkeys. And so it's likely that the areas that are involved in these cognitive functions would have changed more when we go from monkeys to humans, whereas areas that are involved in the basic body functions may not have changed that much. And we saw in the last slide that the human brain is about 1400 grams, whereas the monkey brain is about 100 grams. So in general, there is an expansion of about 14 times.

But the areas that are involved in more cognitive functions would have seen bigger expansion than the areas that are involved in the basic body functions. Scientists have actually calculated these ratios for different areas of how much they have changed going from monkeys to humans. And let's see what these ratios are. And see if you can guess which parts of the brain do you think would have expanded more compared to other parts from monkeys to humans.

So here is the result. This image of the brain basically shows the ratios of by which different areas have expanded. This is the front part of the brain. This is the back side of the brain. And the colors indicate the ratio. So the hotter colors, red and yellow, indicate larger numbers.

And then the cooler colors and the darker colors indicate the smaller numbers or the smaller expansion. And let's see which areas have seen the biggest expansion. So we see that this area in the front and then these areas here. So these are called the frontal lobe areas and these are the parietal and temporal lobe areas seem to have seen larger expansion. Whereas this band here and then this back side of the brain has seen lesser expansion.

And based on this, one could already make a guess about what these areas might be involved in. So it turns out that these frontal areas and these parietal areas are involved in planning and problem solving and memories and cognitive abilities. Whereas this band here, these areas are involved in basic perception and motor functions and these areas are involved in basic visual function. So this is an example of how looking at the evolutionary perspective, how looking at the differences between brains of different species can tell us something about the functioning of the brain. Now let's consider the brains of different humans.

Of course, the brains of different humans are much more similar to each other than the brains of humans and monkeys. And that's because the blueprint for making the brain is contained in the DNA and in our genes. So let's also think about whether we need more number of genes to make the more complex human brain. So here's the data showing the number of genes in different species. And as you can see, the number of genes in humans and mice is similar at about 25,000.

And it is not that much more compared to flies or worms. And in fact, some plants can have a larger number of genes even though they have no brains. So the number of genes does not seem to correlate with the complexity of the brain at all. Although genes must be involved in making the brain, but it seems that it's perhaps there are other mechanisms that determine how these genes are expressed that may be more complex in humans or perhaps non-coding regions of the DNA might be playing an important role in adding this complexity to the human brain. So far in this video, we have seen how the human brain has evolved from simpler organisms and has achieved a staggering level of complexity.

Our brain has about 86 billion neurons or if we approximate it about 100 billion or 10^{11} neurons. And each of these neurons forms contacts with thousands of other neurons. So there are on the order of 10^{14} synapses or contacts between neurons. In fact, in the first two years of our life, almost a million synapses are formed every second. And these neurons have been classified into different classes.

Depending on the zoom level, one could have fewer classes or more classes, but the general consensus is that the human brain has thousands of different neuronal classes. Now in the coming videos, we will see what methods are used in the field of neuroscience to understand this complexity of the brain. Thank you.