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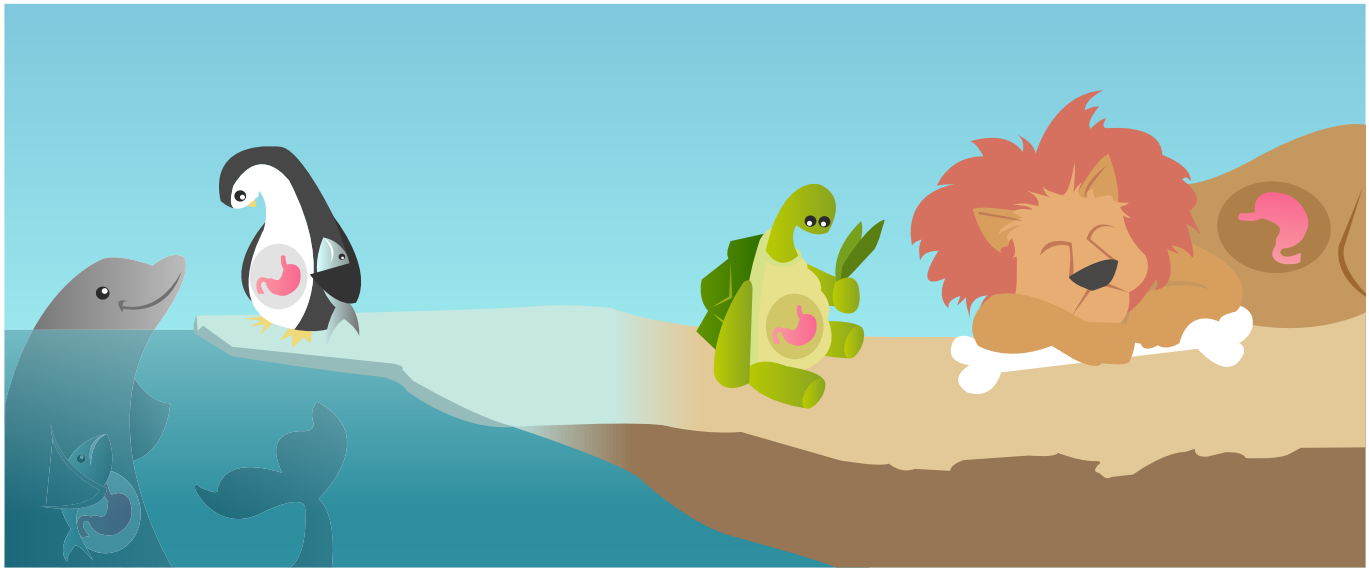

WHAT THRIVES INSIDE; THE WORLD WITHIN THE GUT

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REVIEWED BY:


BRIAN
10 YEARS OLD


ELSA
10 YEARS OLD


YOONSA
9 YEARS OLD

We all have bacteria in our guts, and so do all animals, including birds. These bacteria are good for us in many ways and help to digest the food we eat. We often see similar groups of bacteria in the guts of animals that are related to each other. But it is not clear why this is. It could be because similar animals eat similar foods, or maybe because of other similarities between the related animals. It could even be a result of how closely together the animals live. We performed an experiment to try to work out why gut bacteria are similar in animals that are related, but the results were not as simple as we hoped. Here, we explain the steps we took to try to answer this question.

ANIMALS, BACTERIA, AND "MICROBIOMES"

Colorful feathers, attractive songs, darting, diving, and flying. These are all ideas that come to mind when we think about birds. Most of us can name our local birds and probably think of a bird as a small, flying animal that eats fruit or insects. But what about birds that do not fit this description?

The penguin cannot fly and swims in the ocean to catch fish. The ostrich is flightless and stands taller and heavier than a fully grown man. The vulture seeks out rotten food to eat. As a group, birds are just as different as mammals. Mammals come in all shapes and sizes from bats to dolphins, to elephants, to humans, to hyenas. Despite all the differences between these animals, they all have one thing in common. Every one of these animals is home to billions of microscopic bacteria and fungi, called **microbes**. These microbes live on skin, in the mouth, and especially in the gut.

MICROBE

A general term for microscopic, single-celled organisms. Usually this term is used to describe bacteria, but can also apply to archaea, fungi, and viruses.

Most people call these microbes germs, but the majority of them are actually helpful, and often essential, for the health of whatever animal they call home. In human guts, microbes help us digest food and, in our intestines, they make nutrients our bodies need. These microbes also help us maintain a healthy body and can help us fight off food poisoning and sickness. Over one trillion (that is, 1,000,000,000,000!) bacteria live in the average animal gut. Together, these bacteria are called the **microbiome**. In mammals, scientists have discovered that the gut microbiomes of animals with matching diets and lifestyles are similar. For example, the gut microbiome of a cow and a sheep are similar. But the microbiome of a cow and a lion are not. This tells us that, even though each animal **species**' microbiome is distinct, microbiomes are influenced by the animal's diet and lifestyle. Unfortunately, we have only just started to understand how different each microbiome really is, and why many of the "rules" for how a microbiome looks are still unknown to us.

MICROBIOME

A collection of microbes that live together and interact with each other.

SPECIES

A group of organisms which are considered to be the same. For animals and plants, this is usually defined by their ability to create offspring.

WHAT MAKES A MICROBIOME THE WAY IT IS?

The similarities and differences between the microbiomes of different animals made us wonder if species with similar diets have similar microbiomes, or whether the microbiomes are only similar because the species are related. For example, do a dolphin and a penguin have a similar microbiome because they both eat fish? Or, even though they have similar diets, do dolphins and penguins have different microbiomes because they are not closely related species (Figure 1)? In science, it is common to create a hypothesis, then design an experiment, or a series of experiments, to test it. The results of the experiments are then reported in a trustworthy scientific journal. Other scientists read the report in the journal and come up with new ideas. Our hypothesis was that we would see the same bacteria in birds and animals with the same diet. Because this hypothesis needed multiple experiments to compare the microbiomes of different birds, this would have been impossible to do with a single experiment. To overcome this problem, we performed something called a **meta-study** [1]. A meta-study involves looking at lots of different studies on the same topic and comparing the results from *all* the studies. This allowed us to bring together the data of many other scientists

META-STUDY

A meta-study is a type of experiment that takes data from previous experiments and compares the findings against each other.

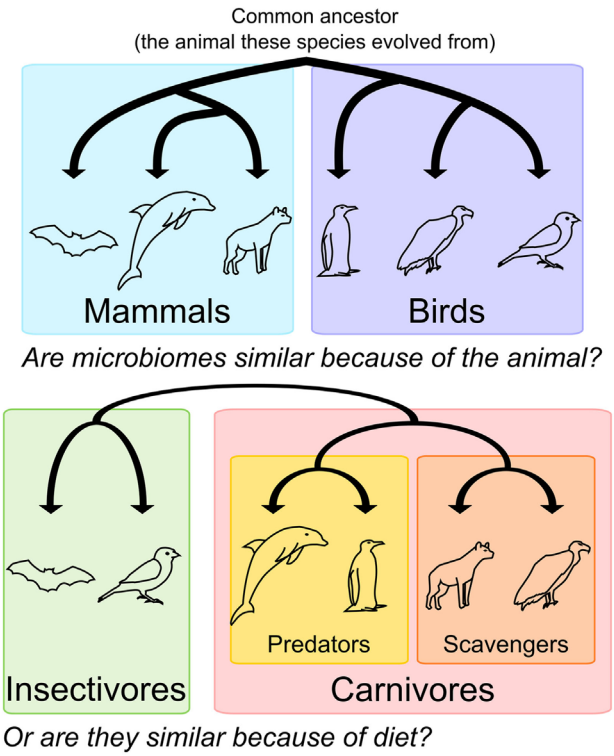

FIGURE 1

The purple box shows some birds (penguin, vulture, and sparrow), while the blue box shows some mammals (bat, dolphin, and hyena). These animals are in separate boxes because they are different, even though they share a common ancestor. There are two general ideas about microbiomes. (1) Microbiomes are similar because the animals are similar (all birds or all mammals, etc.) or (2) Microbiomes are similar because of diet (carnivores, insectivores, etc.) The dark pink box shows examples of carnivores, but it has two boxes that show the type of carnivore. Our hypothesis predicts that microbiomes are similar because of diet.

and identify patterns across all the different studies, which may not have been noticed before.

As we said above, we know that the types of bacteria in an animal's gut are there at least partly because of the animal's diet. Just like us, bacteria have their own favorite foods. For example, herbivorous animals eat plants, so in their guts we find plant-eating bacteria. Carnivorous animals eat meat, so in their guts we find different bacteria. It is easy to assume that animals with the same diet will have similar microbiomes, but there are other things we need to think about as well. The stomachs of humans and other mammals are acidic, but insect stomachs are not, and this difference in acidity affects their microbiome. We knew about two earlier studies that looked at the differences in microbiomes in different ways. One of the studies looked at mammals in a zoo and found that the microbiome is influenced by diet [2]. The other study looked at wild animals and showed that the microbiome is more affected by the kind of animal (bird, mammal, insect) it is living in [3].

CLOSELY RELATED ANIMALS HAVE CLOSELY RELATED MICROBIOMES

We took microbiome samples from a large selection of animals, and this helped us explain why the two studies had very different answers. When we looked at our results, one of the things we found was that birds and

reptiles have only small differences between their microbiomes. This was surprising to us, because we had expected that warm-blooded birds would have a microbiome that is more similar to the microbiome of mammals than to that of reptiles. We do not know for certain why this is, but if you have seen the movie Jurassic Park then you can probably make a good guess. Since birds and reptiles are closely related, the differences between their guts are small. We can link these two facts to make the conclusion that small differences between guts means small differences between microbiomes. Separating animals into groups—insects, mammals, reptiles, birds, etc., is really too simple. As we examine more closely related groups of animals, the differences between their microbiomes are smaller.

WHICH IS MOST IMPORTANT—LOCATION, DIET, OR ANIMAL?

The zoo study, we talked about before, only looked at mammals, which explains why those scientists found that diet was the most important thing controlling the microbiome. The other study looked at different types of animals, not just mammals, so diet was less important. We discovered that, when we looked only at birds, diet is important for determining the microbiome, but it is not the most important thing. We found that the individual bird species we are looking at is much more important than diet. We were missing a piece of the puzzle. What do a lion, bat, echidna, panda, and sheep living in a zoo all have in common? Well, they all live in a zoo. Animals in the zoo are all different, but, because they all live in the same area, they all live with the same types of dirt, dust, and disease. They are exposed to the same microbes, even if their diets make different ones live in their guts. When we did our meta-study, we did not expect this missing puzzle piece to be as big as it was. When animals of the same species live together, they have more similar microbiomes than when they live in different locations [4, 5].

DO THESE RESULTS CONTRADICT EACH OTHER?

Actually, they do not. All of the factors are important: how closely related two animals are, how similar their diets are, and how much they share their environment. But how important each factor is depends on the other two, as well (Figure 2). What this study showed us is that science is not simply a case of true or false. There are many different things that we need to think about when we make hypotheses. And when we make our hypothesis, is it always correct? Of course not—our study proved that. Hypotheses often change as we discover more data during our research. But we learn from the mistakes we make. And when we do find a reason for something, this reason is usually specific to one specific set of circumstances. This means that someone else may find the opposite result when their study looks at a different set of

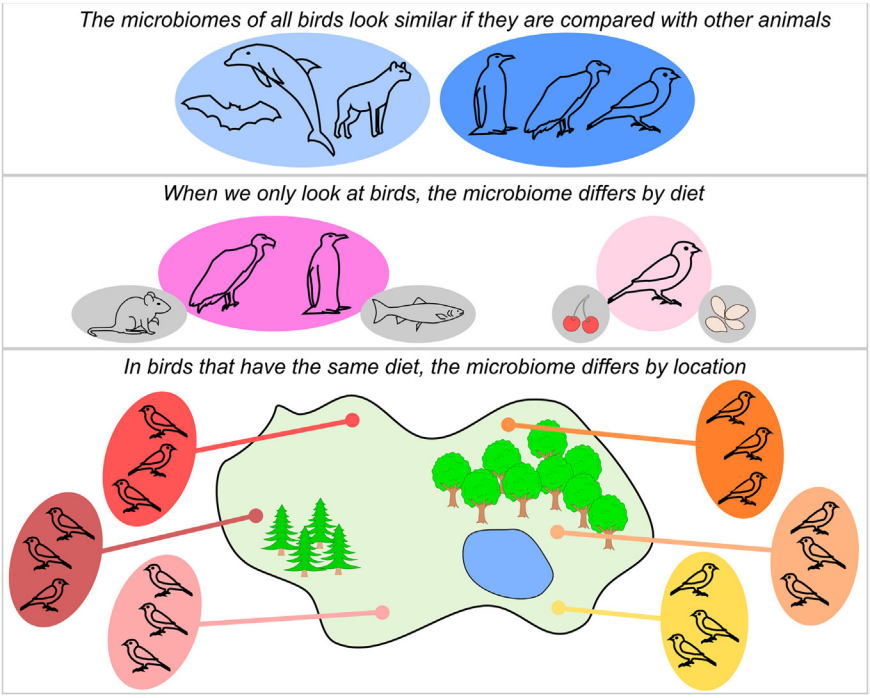

FIGURE 2

We originally thought that an animal's microbiome would be a result of either the type of animal, the animal's diet, or the animal's living location. We predicted diet would be the most important factor determining the microbiome. However, we found it was much more complicated than this. When comparing different types of animals, the microbiome appears to be the same in each type of animal: the microbiomes of all birds were similar. But, when we looked at the same type of animal (birds), there were still some small differences in the microbiomes between birds. So, in these cases, diet is more important. Also, the location becomes more important when the type of animal and the animals' diets are similar. This figure uses birds as the example, but a similar pattern exists for mammals.

circumstances. To us, this is the fun of working in science. While it can sometimes be frustrating, in the end all it does is inspire us to do more research about the world we live in.

ORIGINAL SOURCE ARTICLE

Waite, D. W., and Taylor, M. W. 2015. Exploring the avian gut microbiota: current trends and future directions. *Front. Microbiol.* 6:673. doi:10.3389/fmicb.2015.00673

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REVIEWED BY

BRIAN, 10 YEARS OLD

My name is Brian and I am in the fourth grade. I am 10. I love dogs, playing 2k17, FIFA 17, Battlefront, NHL 16, and RBI baseball 17 on my X-Box. I like playing sports and doing math. I also like Nike and Jordan basketball shoes. I play soccer, basketball, baseball, cello, drums and piano. I like sports books and comics.

ELSA, 10 YEARS OLD

My name is Elsa, I am 10 years old, and am interested in language, Medieval and Tudor history, Religion, Genetics, Svalbard, KalaallitNunaat, and Writing. Some of my favorite books include All The Light We Cannot See, by Anthony Doerr, Counting By 7's, by Holly Goldberg Sloan, The Girl Who Drank The Moon, by Kelly Barnhill, and Where'd You Go, Bernadette, by Maria Semple. I decided to start reviewing articles when my friends, Yoonsa and Brian, asked me ifi might want to be a part of the peer review process. I agreed because I think that science can be fascinating, and it sounded interesting to be a part of the process involved in getting a scientific article ready to be published.

YOONSA, 9 YEARS OLD

My name is Yoonsa. I am in fourth grade and I am nine years old. I live with my parents and my little brother. My parents are both biologists. At our house, we have lots of fish. We are raising baby plecos that hatched from the eggs that I discovered. I wanted to read more about science so that's why I wanted to join Frontiers for Young Minds. In my free time, I like to read and play the violin.

AUTHORS

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David W. Waite is a Postdoctoral Research Fellow at the University of QLD, Australia. He obtained his Ph.D. in the lab of Michael Taylor, where he studied how the microbiomes of birds assemble, and how environmental pressures like antibiotic treatment and host diet affect them. David now studies the evolution of bacterial species, and is interested in the forces that govern their metabolism and let them adapt to changing environments.
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Siân I. Morgan-Waite is an ESOL (English for Speakers of Other Languages) teacher at Westlake Girls High School in Auckland, New Zealand. Siân is interested in performing home experiments and scientific communication. Although not a scientist by training, Siân encourages scientific curiosity and discovery in others, including her students.

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Michael W. Taylor is an Associate Professor at the University of Auckland, New Zealand. He heads a research team which is interested in the ecology of microorganisms associated with animal (including human) hosts, which they study using a variety of molecular and cultivation-based approaches.