

Neuroparasitology with Matt Simon

Ologies Podcast

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Oh hey, it's your friend's nice dad who always pronounces your name wrong, oops, Alie Ward, and welcome to the thrilling conclusion of Spooktober. Here it is! Let's turn our brains right over to zombies, shall we? But actual, natural zombies.

So, this guest, wheuf! Someone I met interviewing for a panel at the beloved Natural History Museum of LA County, I was immediately thrilled to meet another high caliber dork, big dork, who spent his spare time researching our weird world, you're going to love him. He's a long-time science writer, you've likely already read his work in *Wired* magazine's "Absurd Creature of the Week" column. Perhaps you've enjoyed one of his many books such as *The Wasp That Brainwashed the Caterpillar* or *Plight of the Living Dead: What Real-Life Zombies Reveal About Our World and Ourselves*, or *A Poison Like No Other*, his latest book. His books are really deeply researched, they're also hilarious, they're such a joy to read, I'm a really big fan of his.

His *Plight of the Living Dead* came out a few years ago so he was not expecting me in his inbox, but I reached out to him and was like, "Hey old buddy, hi. Hi, remember me? Since you spent years writing a book about zombie creatures and traveling all over the world to interview the best scientists across this wide range of species, may I beg you to talk about it on *Ologies*? Since an ologist is anyone studying something." And he was like, "Sure dude." So, my dream has come alive, and he joined me from his recording studio/closet in San Francisco and it was just a joy to delight in his encyclopedic brain and his very dry wit.

We're going to get right to the episode but first, thank you to everyone who submitted questions ahead of time via [Patreon.com/Ologies](https://patreon.com/Ologies), it costs a buck a month to join. Thank you to everyone posting pictures of yourself in *Ologies* merch that you got from OlogiesMerch.com. And thanks to folks who leave reviews that you know I read on purpose such as this one from Ked98 who wrote, five stars:

Hi Alie (I know you're reading this). I love every episode more than I expect to every time I hit play. Your asides remind me of how my brain likes to be too.

Ked98, we probably have the same fungus.

And with that, let's get into the business of neuroparasitology, the science, and study of organisms who have been fiddled with in their domes. Again, this author studied this study with various people who study it from different angles and species and thus, in the totally legit sense of the terminology ologist, belongs on *Ologies*. So, hunker down and get ready for snake-headed club fungus, bellies of worms, brains of zombies, wasp stings, hapless cockroaches, the attraction of light, moonlit skinny dipping, the philosophy of where I stop and you begin, decapitated ants, and the two of us discussing *The Last of Us* with author and gatherer of all facts neuroparasitology, Matt Simon.

Alie: Things are bad.

Matt: It is. Everything's terrible.

Alie: Yeah. But we can at least talk about ants.

Matt: It's not as terrible as it is for ants, honestly.

Alie: [laughs] Fuck. Bugs are fucked. So fucked. First thing I'll have you do if you could say your first and last name and the pronouns you use.

Matt: Absolutely. My name is Matt Simon, I go by he/him.

Alie: So, you're a science writer. You're very, very accomplished in this field, several books under your belt. When you wrote your first book, did that spark the idea for your next book?

Matt: Sure, yeah, it certainly did. The first book was kind of a roundup of weird stuff happening in the animal kingdom and in that reporting and kind of gathering up those different creatures, I had come across several instances of parasites that have evolved to mind control their host and I decided it deserves a full-length book treatment which is what this is. It is kind of a deep dive into the science as to this weirdly pervasive phenomenon that has evolved many, many separate times across the tree of life. Parasites are, more often than we think, actually mind-controlling the host that they inhabit. [Alie squirms] ["The call is coming from inside the house." Dramatic music.]

Alie: So, more parasites than we realize? It's more than just cordyceps fungus?

Matt: Much more than cordyceps. There are worms that do this, there are wasps that do this, bacteria. So, when I say it's more common than we realize, this is more common than scientists realize. The science of zombification isn't all that old, it's really the past couple of decades it's really gotten going. So, they're finding more and more of these interactions between parasite and host and there's actually a lot of these that we are totally unaware of.

Aside: Matt says that these universes are called *umwelts*. Um-whats? It's a German word that means environment or surroundings as experienced by an organism. Now, *umwelt* is a fun word, but not as fun as the companion term, *Umgebung*, which is an *umwelt* as seen or experienced by a different observer. So, socially, your neighbor Tim who works at an insurance firm might exist in a different *umwelt* than Cardi B, but her Instagram stories provide an entertaining *umgebung*.

Matt: The parasites are playing with senses of taste, and with sight, and with hearing, and smell. We don't inhabit the same universe that an ant does. There might be much more subtle and complex manipulations by these parasites that we just don't even know.

Alie: Is that in terms of chemosensory cues that we just can't even detect?

Matt: Can't even wrap our heads around. It wasn't that long ago that, like, people didn't understand how bats moved through the world until fairly recently in human history. There was a theory for a while, I think it was like 150 years, that bats were actually feeling through the air with their wings, they were feeling by touch. That was the wisdom for 150 years and then they finally did good experiments to show that there's this thing called sonar, these bats sensing the world moving through their world in this completely alien way, to humans at least. So, we are naturally self-centered as people, some of us more than others, but I think as a species we just don't fully comprehend these sensory worlds, these *umwelts*, that these other creatures have.

Alie: I feel like as soon as science does figure out how something works in the animal kingdom, they're like, "How can we weaponize this?"

Matt: Yes. Turn it against somebody.

Alie: Yeah, how can we figure out how to duplicate this in some sort of militarized fashion? ["Gee, I wish we had one of them Doomsday machines."]

Let's go back to you a little bit. Had you been taking notes in a nature journal since you were a child? Did you want to be a field biologist and then there were too many shots you had to get? What's your origin story?

Matt: It was mostly too much school, you know? [*Alie laughs*] You've got to go get your bachelor's and on, and on, and on to get your PhD. No, I've always been totally fascinated by the natural world. I spent a good amount of time as a kid rambling through forests, my grandparents lived in the country, rattlesnakes and such. I was not bitten by a rattlesnake but fascinated by them. Those kinds of things kind of set the stage for me, and I kind of spent my twenties just wandering around aimlessly as a freelance writer, not really having much direction, which I guess a lot of people do in their twenties.

Aside: But Matt loved science and is excellent at studying and communicating it.

Matt: I got to *Wired* in my late twenties and just started writing more about science, focused in on animals and did this column called "Absurd Creature of the Week" that ran for a couple of years, where I profiled these weird evolutionary tricks in the natural world. That turned into the first book, the second book, and then I just wrote a third book about microplastics which is entirely different and entirely more depressing. We don't even need to talk about it here, just forget I mentioned it.

Aside: So, ignore, completely ignore his new and lauded book *A Poison Like No Other: How Microplastics Corrupted Our Planet and Our Bodies*. Forget we even linked it in the show notes, along with his other books about weird animal stuff.

Alie: I feel like the zombification of cockroaches is somehow going to be more uplifting than that book about microplastics, right?

Matt: Weirdly, yes. I can guarantee you. I'd rather think about you know, ants getting zombified.

Alie: Well, [*laughs*] then we'll move away from the true horrors of microplastics for Spooktober and we'll go into lighter horrors such as zombies in the real world.

Okay, so when you started to tackle this subject, you already had some notes and ideas from writing your first book. Did you have to figure out a list of how many neuroparasites or parasitoids... I guess let's start there, the difference between something being a parasite and being a parasitoid. Is there a difference?

Matt: So, a parasite is an organism of some sort that can be like a virus or when we're talking about ants getting zombified, we're talking about a fungus that invades their body and feeds on their energy and eventually kills them in these really, really elaborate ways. Then a parasitoid is one of the parasites that ends up killing its host in the end. So, in the case of the ant, obviously the most famous example, we have lots of examples of wasps that do this in really horrific ways to cockroaches and caterpillars. Yes, parasite; a general energy exploiter. Parasitoid; one that actually ends up killing its host.

Alie: Oh, so one is lethal, and one just keeps you alive for as long as it can to drain off of you.

Matt: Yeah. So, think of a tick is a parasite. Feeds off of your blood, hopefully doesn't give you Lyme's disease, but drops off and goes about its merry way without killing you.

Alie: Mm-hm. On its merry way, like, "See ya! It was so good; it was so nice." [*giggles*]

Matt: "Great meeting, exchanging fluids. See you later."

Aside: And if you're thirsty for more on ticks, Lyme disease, and other acarologically-borne illnesses, we have this great mega episode linked in the show notes below about ticks that will just have you checkin' your crevices forever.

But back to Matt. So, he'd been researching and writing a column for *Wired* called "The Absurd Creature of the Week," but had this giant spreadsheet of *horrifying* critters that many people would call assholes, but others would say are just behavioral manipulators.

Matt: You get into conversations with scientists and just reading through the literature and you find, really, like classes of these behavioral manipulators, different kinds of worms. But there might be hundreds of different species of a particular worm that manipulate different hosts in subtly different ways. These are extremely, interestingly evolved behaviors and manipulations. So yes, it was a matter of finding a list of scientists who would bother talking to me and some of whom I actually was able to visit in the field but a whole lot of reading literature. So much literature. [*Alie laughs*] This is fun to read through, it's not like organic chemistry. Sorry to organic chemists out there. [*Alie laughs*]

Aside: All right, don't tell Matt but the debut novel of Bonnie Garmus, *Lessons in Chemistry*, has been a *New York Times* Bestseller since its release in 2022 and it's about a woman who studies abiogenesis, the origins of life via carbon-containing compounds, which is organic chemistry. And it was instantly snapped up into a TV show for Apple, for which Dr. Teagan Wall of the WGA Strike episode was a supervising producer if you remember that. I think organic chemists are doing fine at the library.

But from the stacks and the journals and the notebooks and the interviews to tucking his pants in his socks and hopefully crevice-checking at some point, Matt got sunburned and dusty alongside the researchers.

Matt: So, we all know about the *Ophiocordyceps* fungus that manipulates ants, that's what *The Last of Us* is based on. But there are *all* sorts of scientists all over the world working on these less well-known interactions between parasite and host. So, I was able to visit a scientist who took me on a hike through New Mexico looking for horsehair worms that do crazy things to crickets. I was able to bother these people for their time and energy, not unlike a parasite actually [*Alie laughs*] with their time and interaction.

Alie: Can you talk to me about horsehair worms, as long as we're there? Wow, you've never seen anything come out of a butt like a horsehair worm, have ya?

Matt: It's... It's an experience. [*Alie cackles*] I was lucky enough to see them both in the wild, on that hike in New Mexico, and in the lab that I went back to with this researcher. So, this guy was nice enough to take me out into the wild and we were looking for bodies of water, which is not a place that you typically find crickets, right? But we eventually came upon this cattle bucket trough, it wasn't really a trough, it was more circular... I don't know anything about farming. [*Alie laughs*] It was where cows drink.

Aside: I think it's a stock tank, just in case you're listening while operating your tractor and screaming, "It's a stock tank!"

Matt: And we looked into here and through the water and we found these wiggling, pale-colored worms, horsehair worms. I think I describe them in the book as *al dente* angel hair pasta. [*Alie chuckles*] So, where did these worms come from? It is a very interesting and horrifying story, especially if you are the cricket.

So, what happens is a cricket is doing its thing, it's hopping along, eating basically whatever it can on the ground, they are not picky eaters. So, they will typically eat something like a mosquito and the mosquito has these larvae, these eggs of this parasite, called the horsehair worm, in that body.

Aside: So, the cricket snacks on this mosquito, not knowing that it is *stuffed* with parasite eggs, like cheese in a crab Rangoon... Yum-yum-yum-yum. Worth it.

Matt: And then once the cricket consumes that, those eggs hatch into larvae, work their way through the tissues of the cricket, which I can't imagine feels particularly good and grow. Sometimes many of these can actually grow in the abdomen of a single cricket. One of them, it's actually quite interesting, one of them will actually snake its tail through the cricket's body and around its brain, [*Alie yelps*] and the thinking there is that it is releasing some sort of chemical to then mind-control the cricket. That mind control entails jumping into a body of water where, again, a cricket is not meant to be, on account of drowning. [*Alie sighs*]

So, once that cricket hits the water, the worm knows to escape because it's actually poking part of its body out of the exoskeleton of the cricket, it can taste that water. Once it is in that water, that's when it makes its break. It wiggles out of the cricket, this very, very long worm. And we were actually able, in the lab, like you do, he just went and grabbed a couple of crickets that had a bunch of horsehair worms in their bodies, tossed them in a little pan of water, and very quickly, these worms, several of them, would just squirm out. The cricket, you would think, that's it for the cricket, what's the point of living anymore?

Alie: Yeah, embarrassing too. [*"You don't need to see this."*]

Matt: You think that would be the death of the cricket. It is not! Actually, the vast majority of them survive.

Alie: Oh!

Matt: Sometimes, again, several of these worms come out of their bodies in this really horrific fashion. So, where this gets extra interesting is around this idea that the scientist was telling me about called the mafia hypothesis. So, we know like the old shake down, "If you don't pay us money, something bad could happen to your shop. We would hate for that sort of thing to happen by our hand or otherwise." So, there's this theory actually that the cricket *wants* to get rid of those worms. So, as the parasite is in its body, it is sucking up energy and nutrients from that cricket, it's quite a burden. There might be a component here that the cricket actually is maybe partly behaviorally modified into jumping into water but also, to a certain degree, would want to, to relieve itself of the burden of these worms, especially given that it can go on to survive perfectly fine. It is not, I can imagine, a fun experience for the cricket to go through. [*"Please... Just leave."* "*Okay, buh-bye."*] But it hops along only to probably eat another mosquito, ingest more worms, and then do it all over again.

Aside: And while I know that you want all the answers buttoned up tidily, a 2021 article titled, "New Definitive Host Record For *Chordodes Morgani* (Nematomorpha) in Nebraska," shrugs, "the life cycle and ecology of the horsehair worm in Nebraska remain unknown." But don't let that deter you from finishing the article which includes tasty tidbits such as, "The male cloacal opening is surrounded inside and outside by bristles that bifurcate deeply," and, "adhesive warts are lacking."

Alie: Do scientists know what part of the brain the worm is wrapping around to poke at to make it say, "Water!?" Or I mean obviously, if it's like, "You know what might help get these things out of my butt is some water." But any idea what's happening in the brain?

Matt: With the worms, it's not necessarily poking into the brain, I think it's getting in the proximity of the brain. They're still trying to work out what chemicals are involved here. But generally speaking, across these parasites, we're looking at things like very reasonable, well-known stuff like dopamine, GABA, serotonin, these sorts of things that serve very different functions in these different creatures across the tree of life and they do of course in the human brain.

Aside: In the case of the crickets and the horsehair worms, studies like the 2011 *Behavioral Ecology* journal article, "Water-seeking behavior in worm-infected crickets and reversibility of parasitic manipulation," found that it wasn't necessarily a great thirst for water that got the crickets to soak their butts but rather, a modification of phototaxis or an attraction to light. And given that these horsehair worms tend to taste water and unfurl out of their hosts nocturnally, they think the glimmering light of the moon on water may be what gets the poor souls to just finally rid themselves of their squirming burdens via a moonlit skinny dip.

Matt: But it is a wildly complex manipulation that has evolved, again, so many times, independently. That's what's so fascinating to me about this. It seems that this is just a tendency for biology, to mind control. And it actually makes a lot of sense because it's actually an excellent strategy if you're trying to reproduce and pass your genes along to a next generation.

Alie: Do they find that it occurs in all kinds of biomes and environments? You talked to me about New Mexico, and I think of it as a very arid place, and looking for water must be difficult for horsehair worms. Does it happen more in extreme environments where resources or certain habitats are scarce? Or is it just everywhere?

Matt: As far as I can tell, it's mostly everywhere. Again, because the science is so new and because these interactions are so complex, scientists are really just beginning to work their way through how much of this is out there, and where it is. So, it's in New Mexico, there are actually species of *Ophiocordyceps* that do this sort of manipulation in North Carolina, in addition to the famous ones that we know of around the tropics. This is very common among worms that infect crustaceans in lakes around the world, doesn't matter where those lakes are. It is so, so pervasive, and again, we're just at the tip of the iceberg because we're stuck in our own *umwelt* here. We're kind of flailing in the sense that we only really know our spectrum of visible light, right, or the sounds that we can hear, tastes that we can taste, and smells that we can smell. There's much more out there, I can guarantee you.

Alie: Well, speaking of light, what other ways are the brains controlled? Is it through electrical impulses? Is it through the amount of light they're getting? Is it neurochemicals? Any idea of other ways that they're telling the brain to do different things?

Matt: I think a really good example here is these worms called acanthocephalans. These go after crustaceans known as amphipods in freshwater lakes.

Aside: Amphipods, there are over 9,000 species on the books, and I did not know they existed until now... Rude. But they live in water, mostly, and their name means that they have feet on all sides of their body. They look like stumpy shrimp but tiny and sometimes they answer to the name Scud when they're feeling up to it and aren't being turned into aquatic zombies.

Matt: So, this is a super fascinating behavior change because it depends on the life cycle of a particular acanthocephalan. So, they will either want to get into a fish or a bird to complete their life cycle. So, they get into the body, this little, tiny crustacean, it's got little tiny hooks, it's actually kind of cute [Alie laughs] in a sickle kind of way, it has sickles in front of its face. It's harmless but it ingests these worms, and the worm then needs to somehow steer it into a bird or a fish that lives, obviously, in different parts of a lake. So, depending on the species, if it wants to guide the amphipod into a bird, it'll actually guide it toward the light, ["Run to the light, baby!"] up toward the surface where it's more likely to get eaten by a bird and complete its life cycle. But the ones that manipulate these crustaceans into fishes, they'll actually keep them away from the surface, they don't want to get eaten by birds because that's a dead end, they're not going to be able to

reproduce in that organism, so they'll keep them in shallower depths but out in the open where fish are more likely to consume them.

So, when we're talking about behavioral manipulation, I think it's *really* important to consider these as vehicles. So, these parasites have, in a sense, extended their own bodies into the body of a new organism. [*Alie squeals*] So, it's not only controlled the behavior of this poor little crustacean to move either onto the surface or into the open to get eaten by a fish, it's assuming its *umwelt* in a certain way, it kind of has eyes that it's using by way of the poor little amphipod.

Aside: Just a side note, Matt writes in his book that this behavioral manipulation was discovered in 1969 when two scientists were trying to get amphipod samples in a lake and some of the creatures clung desperately to their leg hairs and the researchers were like, "These ones are weird. Let's take them down to the lab, let's get to know them." And according to the 2006 study, "Altered host behavior and brain serotonergic activity caused by acanthocephalans; evidence for specificity," amphipods injected with serotonin displayed the same attraction to light as infected subjects. So, serotonin did it. And maybe, maybe psych meds can lift the darkness. Thanks, serotonin.

Matt: These neurotransmitters that we know full well how they work in humans, but they have entirely different functions in other animals. I think the science now is progressing into learning more exactly how these wasps or worms or fun-gee [phonetic] or [ph] fun-guy – however you want to pronounce it – are actually fully manipulating these creatures because it is such an intricate and elaborate process.

Alie: What about those little critters that eat a fish's tongue?

Matt: Oh yeah, tongue-eating isopods. Those, oh my god, those are behavioral manipulators, but I think maybe in certain ways more horrifying, these are little – not always little, kind of big – but they'll get into a fish's mouth in the ocean, eat its tongue and then replace the tongue with itself so the fish can keep eating and the parasite can keep feeding on its energy. [*"Nobody's going to know." "They're going to know."*] Yeah, Happy Halloween.

Alie: First off, how do scientists feel about the term 'zombie'? When you approach them about this book, – which has the best title ever, *Plight of the Living Dead* – were they like "Enough with the zombie stuff," or were they like, "Whatever gets people to care about our research."

Matt: It depends on the crankiness of the scientist, [*Alie laughs*] like anything. Informally, it is totally fine to call these things zombies. Zombie is a difficult term to define in popular culture because there are so many different kinds of zombies now, they'll say it is behavioral manipulation on the part of the parasite influencing its host which... It's a mouthful. Let's just call them zombies but is it a brain-eating human that rose from the dead? No. But it is zombie-esque.

Aside: Just a wee background on this from the 2018 paper, "The Undead in Culture and Science." So, the English word *zombie* emerged over 200 years ago but it comes from the older Haitian French, *zombi*, most likely originating in West Africa. But zombie persons are part of Haitian folklore, they're usually someone who has had a short illness and then dies, is entombed, and then is brought back to life via witchcraft to serve the person who resurrected them, kind of like a finder's fee, I guess. And as you can imagine, from dying and reanimating as a corpse, usually zombies are pretty wiped out, they have a loss of coordination or ataxia, they're not very chatty. And while a lot of horror movies took their cue from Haitian folklore, a BBC episode of *Planet Earth* inspired the video game and subsequent hit TV series, *The Last of Us* starring my future best friend, Pedro Pascal. This game and series kind of launched the spores of zombie animals into all of our brains.

Alie: Speaking of, let's talk about cordyceps. First off, did you watch *The Last of Us*? Did you play the game? How did you feel about it having written this book?

Matt: I have not played the game, but I watched the series. I thought it was fantastic even though there weren't that many zombies. It was more of a people story, which is fine. People are great. But I thought they did really interesting things with the *Ophiocordyceps* that, I'm not sure if this was true in the game as well but I don't know if you remember, there was a point where they're looking out on this vista and there's this mob of zombies that have been parasitized by this fungus, and they're kind of rippling, like the way that they're moving. And they're saying, they're somehow connected because the fungus is growing throughout everything and everybody. That doesn't happen with *Ophio* in real life, but it is, if you've heard of, like, mycorrhizal networks in the forest, so these fungi actually connect trees and exchange nutrients and things like that, there's this constant communication underground.

Aside: We cover some of this in both the Mycology and the Dendrology episodes but yes, tree fungus friendship is real and it's beautiful.

Matt: It's an interesting thing that they just threw in there. I thought it was fascinating but not actually what *Ophio* does in real life.

Alie: Do you know if they had any fungus consultants? They must have, right?

Matt: Yeah, the guy David Hughes that I interviewed in the book, and I went and visited him at Penn State for the book, he's the guy. If you want to know about *Ophio*, go to David Hughes.

Aside: If you ever sit next to a Dr. David Hughes at a dinner party and he says he studies fungus, do *not* let him change the subject. Rather tell him you love his 2010 paper, "Ancient death-grip lead scars reveal ant-fungal parasitism" or let's also not sleep on the 2021 hit, "An agent-based model shows zombie ants exhibit search behavior." And this episode here is an overview of a lot of different zombie animals, but maybe next year I'll camp out on Dr. Hughes' lawn, and I'll ask him to talk to me specifically about this genus, which means snake club-headed. For now, Matt, who has spent much time asking Dr. Hughes and his colleagues lots of questions for his book, will fill us in.

Alie: I do want to know about *Ophio* but because you've studied so many zombies, I'm coming to you. Let's get into it because I feel like that's one that really has captured people's attention. Can you give me a rundown of what *Ophio*, the fungus, does? And which, is it just ants, or does it get anyone else like bees or hornets?

Matt: So, *Ophiocordyceps*, this genus that, again, has hundreds of different species that each specialize in a single species of ant because these manipulations are so complex. You'll hear about it infecting caterpillars and in fact, this is used in traditional Chinese medicine. So, it infects the caterpillar in the ground and manipulates the caterpillar to point its body upwards, vertically in the dirt. The fungus kills the caterpillar and grows out of its body as a stalk that comes out of the ground. It's pretty cool. That's not a particularly complicated manipulation because caterpillars, I love them, they're not particularly complicated creatures, for all their charms.

So, what *Ophio* does with ants is by necessity, wildly complicated. So, think about what an ant colony is; it is a bunch of sisters working really hard to further the colony. Ants do not like intruders, as you might have known from stepping on a colony. ["Ow! Ow! Ow!"] They have certain ways to detect smaller intruders, so smaller insects, that sort of thing. They have this thing called social immunity; each ant is a worker but also a sentry that is sniffing out trouble coming into the colony. So, if you have a sister that is acting weird, maybe stumbling around, they're not sentimental about this, they will pick up that worker, drag her to a graveyard, and dump her because there could be something wrong, some sort of disease that she has that she could very

easily spread through the whole colony because these are ants in very close contact with one another. And that is a major problem for a parasite, like *Ophiocordyceps*.

So, what it has evolved over many, many generations is this intricate manipulation of an individual ant. It begins as a spore that sticks to the cuticle of an ant, the exoskeleton. At the same time that it's building up these enzymes that are kind of rotting away that exoskeleton, it's also building up pressure. So, it's the pressure equivalent to what's in a 747 jet tire. ["Boom."] So, what happens is the enzyme weakens the cuticle, it explodes through it because of that pressure and then injects that fungus into the ant's body. The ant is pretty much done for at this point, but the issue here is that if the fungus were to grow thoroughly throughout its body, you would assume that there would be some sort of behavioral problem with the ant. I don't know, I would feel a little weird if this was happening to my body and start acting strange, going into convulsions would probably be the least of your worries. So, if that were the case, some other sister would see that, pick up that ant, dump her out of the colony, and that would be the end of that fungus' life cycle.

So, what it has evolved is all right, don't want that to happen. It is somehow growing not only through the ant's body but growing through its muscles and actually ripping apart muscle fibers and growing in between them. The scientist that I had talked to, David Hughes, for the book, I have a quote in the book of him saying that it might be that we're actually seeing a sort of puppet master at work. If the fungus is growing through the actual muscles, it might actually be controlling individual muscles. It's also growing around the brain, the worm is kind of getting in proximity to the brain of a cricket, but it never infiltrates the brain itself and it is dosing that brain with chemicals. So, all the while this is happening, again growing through individual muscle fibers, the ant is not acting strange because that is the end of the life cycle if it is found out. So, it does this for 20-21 days, growing, growing, growing through the body of the ant until the time comes when it wants to finish that ant off, its vehicle is no longer useful to it.

So, it orders the ant to walk about 10 inches off the ground and bite down on the underside of the leaf, so it's hanging upside down, biting into the vein of that leaf. It then kills the ant, dispatches it, and then grows out of its mouth and then further attaches the mandibles to the leaf vein and then grows as that kind of characteristic stalk out of the back of the ant's head, releases more spores, hits more of the colony soldiers and workers below, and then that's how it keeps perpetuating over and over and over. It is, like, consistently ten inches off the ground where the humidity and temperature are just right for the growth of the fungus. How does the fungus know how to do this? Well, it doesn't. It has evolved over many, many generations by trial and error to get it just right, like this.

The weirdness of that cycle itself through an ant that goes on to infect more in that colony, gets even weirder. So, they're finding that not all these ants that are infected with *Ophio* do that. Some of them actually wander outside of a colony; they just walk in a straight line as far as they can and then do the same thing where they bite on a leaf but far away from that individual colony. The theory is that the fungus is actually trying to get to other colonies so if it somehow wipes out that whole colony, it doesn't want to because it wants to keep going. If it kills off its host entirely, that's not good. But it's like the fungus is sending out scouts to try to infect nearby colonies and perpetuate its cycle over and over and over again. Again, the fungus isn't thinking about this, but this is the majesty of evolution and natural selection. This is just the system that evolved in lockstep with the severe measures that ants have to keep themselves healthy and to keep the colony safe. The fungus is like, "Oh, that's cute. How about this? I'm going to invade your body, muscle tissues, and mind, and then dispatch you in this totally creepy way that will someday be immortalized in a video game and TV show."

Alie: [laughs] And there are no chemosensory clues for 21 days that an ant is being puppet-mastered by a fungus?

Matt: Yeah. So, here's... Right, this is where it gets extra interesting. Ants inhabit this sensory space that is totally foreign to you and I who are, you know, we have great eyesight and pretty good hearing, but we're largely visual creatures. Ants are using pheromones to communicate. So, while that fungus is growing through the ant's body, it has to somehow make sure that it doesn't smell weird, right? It's a completely foreign substance taking up, like, half of the ant's total body weight, which is a lot of fungus in an ant. It is somehow evading detection, not only by manipulating the behavior of the ant but somehow manipulating its scent so the sisters don't smell something strange and throw that invader into a garbage heap outside the colony.

Alie: Okay, if they throw sick members in a garbage heap outside the colony, do the sick members ever make it back or are they usually so almost far gone there's no way they can make it back from the graveyard?

Matt: Yeah, if you're that far gone, you're that sick, it's... [chuckles] It's brutal, right? I love ants but that's no way to treat your sisters. [*"She's the least exciting to look at so... she can be out."*] But it's for the good of the colony. They don't want some sort of virus, bacteria, fungus to run wild throughout the colony. I feel like these sisters are more than happy to make the sacrifice; they live to further the colony and to further the queen's reign and they want to make sure that nothing can interrupt that.

Alie: Yeah, they're like, "Take me out if I start being weird. Just, buh-bye."

Matt: "Unceremoniously dump me in a graveyard."

Alie: Yeah. I hear that they even kind of employ the older sisters to take them to the graveyard in case they die on the way.

Matt: Yeah, I love this stuff. It's so goddamn clever but not intentionally or consciously clever, it's just that evolution thinks this stuff up— I'm anthropomorphizing here. It's thinking this stuff up because it is solving problems for these organisms. In the case of the fungus, it needs to solve the problem that it's going to get found out if it's not careful. It wasn't the case that 5 million years ago, *Ophiocordyceps* showed up like this, all of a sudden. It was a step-by-step process, it got better and better and better at not getting detected and better and better and better at not positioning these ants ten inches off the ground where the temperature and humidity are perfect for its development. It was piece by piece and it has landed on what is, in 2023, a super interesting thing for us humans to look at and put into video games and TV shows. But this has been happening for a very long time.

Alie: Mm-hm. Did you ever get to see this in person? Do they grow colonies to test things? How is all of this info gathered?

Matt: When I went to the lab at Penn State, they have colonies there. I couldn't see an infection in progress, but he brought out a bunch of ants that had the stalks growing out of their heads; super fascinating and horrifying really. So, it's actually done – and this is why the science is kind of just getting started – it's done by fieldwork. You've got to go out and you've got to sit in a damn jungle for weeks on end. If it's a 21-day growth cycle for this fungus in an ant, you've got to go out there and put flags in the ground, you've got to track individual ants, you've got to look at trails and things like that. It is truly amazing fieldwork on the part of these scientists.

I had also mentioned that they have been finding these sorts of fungus in North Carolina which at face value doesn't make sense. *Ophio* is in a tropical setting, it's got the right humidity and temperature ten inches off the ground, and it's got leaves all the time that don't fall off those trees

that it's able to bite onto. Where the North Carolina variety gets extra clever is that it doesn't order its ants to bite down on the vein of a leaf, it orders them to bite onto twigs in a tree because if the winter comes around and it hasn't completed its life cycle, leaves can fall and it doesn't fall, it stays there and comes out the next spring or summer. So, it just gets weirder and weirder the more that scientists go out in the field and find these sorts of things. But yes, they can somewhat replicate it in the lab but it's nothing compared to being out in the actual nature.

Alie: I mean, how big is an ant's brain? Like, the size of a pinhead?

Matt: It's miniscule. But so is the fungus, right? It's growing as this network through the ant's body. These are very, very small scales and it's not like it's an easy thing to take over. An ant brain may be small, but its social behavior and interactions are extraordinarily complex so just the fact that it's been able to evolve this not only once but evolve to target individual species for each individual species of fungus is truly astounding.

Aside: Okay. So, an ant noggin has a quarter of a million brain cells but is still only 0.1 microliter which, if you're like, "That number means nothing to me." Same. According to beep-boop-beep-bop calculations, that is one million times smaller than your brain, give or take several thousand ant brains because I don't know what you're working with up there.

Alie: You know, I see cordyceps in supplements a lot like brain boosters and energy boosters. Completely different cordyceps?

Matt: That's probably the caterpillar one that I was talking about. It's probably very expensive. I've never used this supplement, but that stuff is very rare or it's fake, I don't know. Just go to a doctor. [*Alie laughs*] Have a doctor tell you what's wrong with you, don't take a fungus as a supplement.

Aside: One reason you might not want to take *Ophiocordyceps* supplements is because it costs more than gold. But scientists have been able to cultivate another species via insect hosts in a lab and they say the fattier the better. The compound molecular biologists are after is something called cordycepin, which some studies have shown to stimulate the immune system while also being anti-inflammatory. However, studies are mixed, opinions are still out, I am not a doctor, there's still a lot of research to be done. So, dive into the library before you bank on a zombie fungus to save your life. Speaking of research...

Alie: You know, I know the bibliography in your book is dazzling, it's *so* exhaustive. Did you ever talk to any scientists who named their zombie subjects after movies or zombie lore?

Matt: I do have a really good species name from the book, this is one of the acanthocephalan worms, this is the genus is *Microphallus* [*The Price is Right loser horns*] which is tiny penis. [*Alie laughs*] And they are worms and I guess they look like tiny penises. But don't all worms in a sense, look like penises to one degree or another? I don't know.

Alie: I guess, but there are some worms that are like 30 meters long.

Matt: That is true.

Alie: So, I don't know. I guess it's all relative.

Matt: That is true. So then, within this genus, there's a species called *Microphallus hoffmanii*, named after somebody named Hoffman. [*Alie chuckles softly*] So, it's Tiny Penis Hoffman. I don't know who this person was if it was a gag that they were in on, but I find that purely hilarious.

Alie: Maybe it was an academic feud.

Matt: There are a lot of those out there so it very well could have been. I actually went out of my way to try and track it down for the book, but I couldn't find any information on who did this to poor Hoffman.

Alie: Maybe they scrubbed the internet.

Matt: Maybe.

Alie: They're like, "Uhh, just get rid of it."

Aside: I searched way too hard for even the tiniest mention of a science feud that could lead to such brutal taxonomic retribution, but I came up with *nothing* except that *Microphallus hoffmanii* was once called *Microphallus ward*, 100% true. [*Echoey playback of Alie, "I don't know. I guess it's all relative."*] Let's move on.

Alie: Okay. Wasps that sit on top of a cockroach and use its antennae as reins; this is a thing?

Matt: This is a thing. I feel like I'm a broken record at this point... It gets even weirder. [*Alie laughs*] Yes, this is a jewel wasp, and I was actually able to see this happen in a lab, and it was full-tilt horrifying. So, a jewel wasp is much, much smaller than a cockroach, which is its host.

Aside: I needed to understand the scale, so I enjoyed some photographs of this beautiful metallic green, slender killer with its sad hapless beefy victim, and I've never wanted to soothe or protect a cockroach more. But the size difference is like if a German shepherd was attacked by a corgi, who rode its back, injecting it in the brain with a butt knife.

Matt: And when you're much, much smaller than your host, you have trouble overwhelming it. So, what happens is that in a flash, in the blink of an eye, the wasp will kind of saunter up to the cockroach, leap on it, and drive its stinger in between its two front legs. This paralyzes the two front legs so the cockroach can't bat away what's coming next which is the wasp pulls out its stinger and jams it through the cockroach's neck and feels around in the cockroach's brain with its stinger [*squishing sounds*] for two very specific spots where it injects venom [*goopy splat*] it then pulls out its stinger from the brain surgery and steps back and the cockroach, instead of freaking out and attacking the wasp, as I would try to do, it just kind of stands there and it obsessively grooms itself. This might have something to do with part of the venom component being dopamine, which is involved in grooming, in insects like the cockroach.

So, while the cockroach is occupied, the wasp runs off and finds a burrow and comes back to the cockroach, bites off its two antennae, and drinks its blood [*"Yum."*] then grabs onto the nub of the antennae and drags, I guess drags isn't really the right word because it's so much smaller, but kind of guides the cockroach toward the burrow. And the cockroach, instead of flying away, freaking out, comes along willingly and just kind of saunters over to the burrow. The wasp jams it in the burrow, comes inside with it and lays a single egg on its belly, then gets out of the burrow, and covers it up with rocks to imprison the cockroach. So yeah, you can see what's coming.

What happens is the egg hatches interest into a larva, begins drinking the juices of the cockroach, eventually gnaws through its exoskeleton and gets inside the cockroach's belly, [*"Down into my belly. Mmm, mmm, mmm."*] grows bigger and bigger and bigger on its nutrients and at some point, decides to dispatch the cockroach, consume the rest of its body, and then emerge from the burrow as a fully nourished adult. It is... The only thing that makes me feel kind of okay with what's happening to the cockroach is maybe that it's so out of it from the sting to the brain, in two spots, that it doesn't know what's happening. But I really could not imagine a more horrific way to go. [*Alie shudders*]

So, again, *Ophiocordyceps* involves this super complex interaction between a fungus and an ant. Why can't the jewel wasp just sting a cockroach to death and lay an egg on it? Well, by locking it alive in a burrow, a tomb really, it provides a steady source of fresh food for its young that is not, food is not rotting so it's better nutritionally. It's like a little take-out meal that it always has to kind of nip at. And yeah, it's just... It almost makes you feel sorry for cockroaches. I'm not quite there but I can see how some people might.

Alie: I'm trying to love cockroaches, [*deep breath*] I really am. This makes me more sympathetic to them, for sure.

Matt: What brought this on, you trying to love cockroaches?

Alie: Because it's not fair that I don't. I love almost every other bug out there, I've learned to appreciate wasps. I have yet to do a cockroach episode but they're the one bug that I just don't want anywhere near me unless they're straight from a terrarium and they've been eating, like, organic bananas their whole lives. I think it's because I've seen so many, like, eating trash. But I eat t- I mean, we eat the same pizza. That was my pizza a second before I dropped it on the sidewalk. So, you know what I mean? I know I need to give them a place in my heart... once I get over the gag reflex.

Matt: Yeah. I'm with you, I'm with you. [*"Thanks for listening."*]

Alie: What about tarantula hawk wasps? So, this happens, does this tend to happen mostly in arthropods?

Matt: Yeah so, the tarantula wasp, the hawk wasp, is super fascinating. It's not in the book per se, it is not really a zombif- Well, I guess kind of, maybe it is. It's got maybe the worst sting on planet Earth, at least as humans feel it. I did a story years ago where I interviewed a guy who got stung by one of these wasps and he said literally the only thing you can do is to lie down and scream. That is the only way you're going to get through this. It passes, it's not a very long-lived sting but just buckle up buttercup, this is going to be a rough ride. It is so excruciating.

Aside: I know what you're thinking. "What about the bullet ant sting?" your brain says, as was so colorfully recalled in the Myrmecology episode with Dr. Terry McGlynn, who has been stung by one.

[*Clip from Myrmecology*]

Terry: I've had several students intentionally get themselves stung by bullet ants because they wanted to know what it felt like.

Alie: And? And???

Terry: And it really hurt! [laughs]

Alie: What did they do? What kind of reactions happen?

Terry: They just scream their heads off and then use all kinds of cursing. ["You dort'n, no good, damn nipple band, gunk stinkin' crisp!"] I've worked with bullet ants. I've published a few papers on them and I've only been stung by them once, and that was in the lab when I was being dumb. It's possible to work with them and not get stung if you just treat them with respect and understand how they behave.

Alie: Well, hello! What happened? What happened?? Tell me everything. You were in the lab, you got stung by a bullet ant? Where? How? How?!?

Terry: So, I was in the lab, and I needed to weigh this ant because we were doing experiments with microbes in their guts. To weigh the ant, I needed to put it in a container and

weigh the ant in the container, then you subtract the weight of the container. But I realized that when I weighed the cup, it didn't have a lid on it. And I was like, "Oh, I need to weigh a cup with a lid." But I wasn't thinking that the cup that had the lid on it was the one that had the ant I was weighing in it.

Alie: Oh no!

Terry: I just wasn't thinking. So, the moment I got the lid off...

Aside: PS, if you haven't already, now would be a good time to cover the ears of your children or my mom.

Terry: ... you know, it just got me right on the tip of my finger and I was like, [gradually deepens and slows to a stop] "Fuck, fuck, fuck, fuck, fuck, fuck, fuck!" And I flung the ant somewhere in the balance room and it was roaming around. Meanwhile, I have this sophomore in college, I'm showing her how to do this experiment for the rest of the summer and she sees this. I was like, "Oh my god." It was so bad. It was really, really bad.

But how does it compare to the blue-black-amber winged beast of the tarantula hawk wasp? Okay, well there's this bug guy, his name is Justin O Schmidt, who apparently is cursed and has been stung by just every painful thing. Who better to formulate the Schmidt Pain Index? Literally, no one because no one wants to go through that, so we all trust Justin's accounts. So, Schmidt says that the tarantula hawk sting feels like, "A running hair dryer that has just been dropped into your bubble bath," but that fades after a few minutes. The bullet ant sting, however, he describes as, "Pure intense brilliant pain that can last up to 12 hours." The point is, just don't piss off a tarantula hawk wasp, my babies.

Matt: This wasp did not evolve to cause us pain, it's another really beautiful wasp but it goes after tarantulas. It stings the bejesus out of them and it's big enough to actually work and drag away the tarantula and put it in a burrow, so it doesn't have to do this complex behavioral manipulation that the jewel wasp has to, but I would not go anywhere near one. It's in the desert in the Southwest. If you see a wasp, walk the other way.

Alie: Yeah. I've seen them in real life and they're *gorgeous*, but I get excited because that means there are tarantulas around.

Matt: Oh yeah. This is why I'm an indoorsy person, by the way. [*Alie laughs*]

Aside: PS recently I was on a hike in the Santa Monica Mountains, and I saw a tarantula in the wild and it was the most thrilling celeb sighting I've ever seen in LA. And in the late summer, man spiders go lumbering about, brave and horny, and I got to witness one with my wide eyes.

Anyway, back to other scary things, like if you can turn into a fungus zombie, which was on the vulnerable minds of patrons Jenn 'Squirrel' Alvarez, Fyreglass, Holly Giorgio-Dundon, Emily Burns, Kai Kishimoto, Dave Brewer, and Mitch.

Alie: Can any of these cordyceps, can they infect humans? Or is it just mammals who are like, "No, we're too warm. Don't worry about it."

Matt: We are in, luckily, no danger here. So, there have been reports, you can get infected by a fungus, fine, like a foot fungus, right? [*"It's a nail fungus infection."*] It's not in your brain, it's not manipulating your behavior. These are so specific in their manipulations that there's just no way short of, I don't know, 10-15 million years of very specific evolution where the fungus somehow

evolves away from ants and into humans. But why would it? Ants are so abundant on planet Earth, it's a constant massive food source for these fungi to actually do their thing. So no, do not worry.

We, of course, as humans do have behaviorally manipulating parasites, but fungus is not one of them. *Last of Us* is a great rendition of what might happen but honestly, I feel like it's so much more fascinating what it's actually doing to ants versus what it could theoretically do to humans.

Alie: [*squirms*] I want to get to those questions about humans. So, let's ask some questions from patrons. Can we? May we?

Matt: Love it.

Alie: Nice, okay.

Aside: But before we get there, a quick detour to donate to a cause chosen by Mr. Simon which is the World Wildlife Fund which works in over 100 countries to conserve and restore biodiversity, to reduce humanity's environmental footprint, and to ensure the sustainable use of natural resources to support current and future generations. Find out more at WorldWildlife.org and that donation was made possible by sponsors of *Ologies*.

[Ad break]

Okay, let's see exactly what is on your minds. Okay Greg Walloch, Leila Laco, Earl of Greymalkin, Tigeryuri, and Cyntia B want to know about toxoplasmosis. Greg asked: Does toxoplasmosis turn a person into a crazy cat lady like it does with rats? Leila Laco wants to know: Do toxoplasmosis infections really change peoples' actions and personalities or is that flimflam? Any idea?

Matt: Great questions. This is a very fascinating case of a parasite that is probably, in some way, some subtle ways, manipulating human behavior. So, toxoplasma, this is a microbe that does not belong in humans. Its life cycle actually goes between rats and cats. So, in order to complete its life cycle within a rat or a mouse it needs to get eaten by a cat, and to do that, it actually manipulates the behavior of a rodent to not only not be afraid of cats but to actually be attracted to their urine. Bad survival technique on account of needing to get eaten very quickly. But this, just like *Ophio* is mind-controlling ants, just like those acanthocephalan worms are kind of piling around the amphipods in those lakes, the microbe is using those rodents as vehicles to get into cats. So, if they're getting into cats, they're coming out in cat poop, and this is why pregnant women should in no way be anywhere near cat poo because this has the toxoplasma in it, and from that you can get toxoplasmosis which is very dangerous for the developing child.

Aside: Okay, the CDC echoes this, and pregnant people, if you *must* change cat litter, do so with gloves, and PPE, and wash your hands. And also, make someone else do it because you are growing a child and that child could develop vision loss, seizures, or cognitive difficulties if infected in utero. And yeah, millions of people have toxo, actually billions, about 10% of the American population but they think 50% worldwide. Outdoor cats and stray kitties are more likely to have it from hunting infected animals. So, this is another vote for keeping your cats inside, you can see the *Felinology* episode for more on that. And yes, toxo, it's not just for litter boxes, according to the CDC, it can live in the environment for many months and can contaminate soil, water, fruits and veggies, sandboxes, grass, where animals graze, or any place where an infected cat may have left you a turd. Gardening? Wash your mitts, wash your veggies. So, mind-controlling parasites that are scarier than ghosts who are just dickin' around in the attic with some chains.

Matt: There's a growing bounty of research showing some behavioral issues around people who are infected with toxoplasmosis. This is, I think about a third of the population and it's been linked to

aggression, there was a study that found that people tend to be in more car crashes with toxoplasmosis [*Alie gasps*] which also might be a link to aggression.

It really comes down to I think really this fallacy that we as humans are fully in control of what we are doing. There are all sorts of things happening in our brains that we have no control over. I'm not a specific believer in free will if you can believe it, but there are also these outside influences. So, it's like, you can get toxoplasma in your brain, it's not intentionally doing it but because we're mammals, we're related to mice and rats (in the way past but still related) it's just kind of a byproduct, it does some strange things to our brains as well. And then it makes you think, well what other kinds of microbes have gotten in our brain and are slowly affecting our behavior? It's a good question and maybe not one that many people want to think about.

Alie: Earl of Greymalkin and Kristen Rosenblum want to know about rabies. Kristen asked: What are different methods used to take over the nervous system? I'm thinking about rabies.

Matt: When you think about what rabies does to people, which is truly terrible, and the myth of the zombie, they align very well. So, rabies is not meant to be in humans. You get it in raccoons, coyotes, these sorts of things that undergo these really diabolical manipulations. So, the virus makes the animal hyper-aggressive, it proliferates in the saliva so when it orders, basically, that creature to bite onto another animal, that's the way that it transmits itself between different hosts.

Of course, we are not meant, as humans, to be part of that life cycle for the rabies virus but we happen to be also manipulated by it, again, this is truly diabolical stuff. People with rabies, it's essentially a death sentence. Almost nobody who has contracted rabies has survived it unless you get the vaccine. I want to say this, I truly mean, this is not like, "Oh, I guess I *should* go watch this sort of thing." There are videos of this; if you come across one don't ever watch it. It's really, really difficult stuff to watch because you can see the person struggling. They can be hyper-aggressive, like a raccoon or a coyote could, but they're also afraid of water. So, this is a manipulation on the part of the parasite for its other hosts to keep those animals from drinking and washing the virus out of its mouth so there's more of that virus for when it bites on, it's better able to transmit. It's a truly horrific thing to happen to humans and it's probably the basis of the zombie myth, this person that is locked up, kind of mumbling and really struggling.

Aside: I know he said not to and of course I did. And yeah, grainy footage of blurred children's faces, one agitated in a hospital bed, recoiling at water offered by his really despondent mom. It was really gutting and to know how grim the prognosis is, it's just awful. And while most infections happen with a bite, you can contract rabies from saliva on an open wound, and once it is contracted, rabies is so deadly that even if you wake up with a bat in your room, the medical protocol is post-exposure prophylactics, which is a series of shots just in case you were scratched or bitten in your sleep. Obviously, with larger infected animals, it's easier to discern if you've had a bite. So, while rabies deaths are rare in the US, be careful. Make sure your pets have their shots, rabies is a real 0 out of 10. Would not recommend. No stars on Yelp. Double thumbs down.

Alie: A couple of people wanted to know, OtterKhaos AKA KrisP wanted to know: According to the World Wide Web, there's a powder that can be inhaled (generally unwillingly) which makes the inhaler easily manipulated. How about the veracity of "Haitian zombies" with tetrodotoxins from puffer fish? Anything else in human beings that would count as zombification? Or does one have to be alive to do behavioral manipulation? Or can a plant do behavioral manipulation?

Matt: Yeah, you've got to be alive. So, like, the proper zombie in popular culture comes back from the dead, right? As far as we know, that's not possible for people. Luckily! That would be very problematic if people started popping up from the dead.

Alie: It really would. Legally, having to go to the courthouse and having to reverse records, that would be such a nightmare.

Matt: A lot of paperwork.

Alie: So much paperwork.

Matt: We don't need that; we don't need that.

Aside: Tetrodotoxin, PS, is the magic pixie dust derived from puffer fish or newts and it can cause very unfun reactions like numbness and barfing and motor paralysis, respiratory arrest, and the big D that sends you up to heaven. Cooking doesn't even neutralize it and it can get you via ingestion, injection, inhalation, or a break in your skin, it's an opportunist. And it apparently blocks fast voltage-gated sodium channels in the nervous system. But more importantly, there's no antidote so if you're on vacation and your drunk brother-in-law challenges you to try the puffer fish, just say, "No, man." Or say, "I hate you, Derek, everybody hates you."

Alie: Do you think that human beings can be zombies to other human beings by engaging in behavioral manipulation?

Matt: Oh my god, I think that's the main route of our behavioral manipulation. [*Alie laughs nervously*] I'd almost rather be taken over by a fungus than be manipulated by people for the rest of my life.

But yeah, it could set these really sticky questions about free will, right? Like, if we are able to fully parse the way that consciousness works and realize that, oh man, we're just chemicals and electricity and gobs of fat in our brains. If parasites are so proficient at hijacking these systems, reaching across the tree of life, like, a fungus is an entirely different animal— Not even an animal, an entirely different organism than an ant. They're fully assuming the body of another organism. It's kind of a profound question. It's not my profound question, I didn't think this up, but when does an ant that's infected by *Ophiocordyceps* stop being an ant and start being something new? Something like a zombie. What is the dividing line there? It's weird to think about but it's again, not just happening to ants, happening all across the animal kingdom.

Aside: So, we've done Quantum Ontology about the universe and if it's real but if anyone is up for a Metaphysical Ontology episode on the philosophical study of being, that one might be the scariest of all because it's much easier to just play video games or scroll on TikTok instead of feeling our feelings and confronting our own existence. Anyway.

Alie: A bunch of people had good questions about applications in humans. Emily Staw-Fur, Dave Cannon, Isabelle Leclerc, Mark McPhilips, and Ann Marie Wierzbicki wanted to know, in Ann Marie's words: What are neurologists saying about parasitic mind control? And Emily asked: Is it possible to target only certain parts of our brain for mind control? Could we use something like this to treat depression or other mental illnesses?

Matt: Yeah, great questions. In the book I visit a scientist at NYU who is working with rodents with this fascinating system, actually injecting materials that break into individual cells in the brain and respond then to light. So, she's able to shine light into the brain and activate parts of that brain, one of which being for aggression, it can actually make these rodents much more aggressive. So, learning more about how the brain operates in these ways... I don't think she's looking to do the same thing to humans like some sort of diabolical lab where she's shining a light in people's brains and making them angry. [*I'm so piiiissed.*] But I think of this really fascinating notion that as we learn more about the human brain, what makes it tick, hopefully, that doesn't go in the direction of somebody saying, "Well, if we know what makes it tick, these are the ways I can behaviorally manipulate those brains like *Ophiocordyceps* might in a South American jungle."

Aside: So, in *Plight of the Living Dead*, you can see the chapter titled, "The Brain-Hacked Rat that Wore a Funny Hat and Destroyed the Notion of Free Will," which details the work of scientist Annegret Falkner, now at Princeton, who uses optogenetics to stimulate rodent aggression through fiber optic cables in the hypothalamus, and very specifically infected subjects. It involves a bit of neurosurgery, virology, and technology to accomplish this mind control and is very complicated, it seems a lot easier just to give the mice tiny little phones and show them pictures of richer, prettier mice with better lives. That's probably a faster process too. On that note...

Alie: Buddy Freakin' Guyerson and Andrew McAdams both had questions. Buddy's words: What are your thoughts on fast versus slow zombies? Andrew asked: When humans become zombies, do you think they're going to be slow-moving like *Dawn of the Dead* or will they have dramatically increased physical abilities?

Matt: Love the question. I think that looking at these parasites in the natural world gives us some very fascinating windows into this. So, if you are *Ophiocordyceps* infecting an ant, you don't necessarily need to work about the speed with which you're controlling that ant, you just don't want it to look weird enough that it gets discovered by its sisters and dumped in the graveyard. ["Bye!" "Bye!" "Bye!"] but there are other parasites out there, so like the acanthocephalans that I was talking about that affect the little crustaceans in the lakes, they need to make sure that their hosts are not only in full control of their bodies but able to get to those specific parts of the lake either to the surface to be eaten by a bird, or farther down the water column to be eaten by a fish.

So, when we're thinking about parasites turning their hosts into vehicles, into these sorts of zombies, do you want a fast zombie sometimes? Yeah, for sure, if you need it to complete your life cycle. Does the horsehair worm in the cricket need it to be well enough to get into that body of water? Absolutely. But there are others like the jewel wasp and the cockroach, there's no speed considerations here, it just stupefies the host.

So, what would be the case in humans? I would argue that it would be a speed thing. If it's about the virus ordering around the human host to bite more humans, you don't want a slow, bumbling zombie host, you want a *28 Days Later*, super speedy zombie that can bite more and more people. From an evolutionary sense, if the virus can pass itself off onto more and more hosts, it's able to further more generations of zombies, that sort of thing. So yeah, looking to the natural world, I would vote on us becoming fast ones. I feel like that's a controversial topic and I'm probably going to get dragged for it on the internet though. ["What a drag, huh?"]

Alie: [laughs] Sarah R-L wants to know: Have you ever dressed as a zomb-bee for Halloween? Or an *Apocephalus borealis*? I don't know what that is but maybe you do.

Matt: Oh yes, the decapitating flies. I have not dressed up as any of these animals, unfortunately. I feel like at a Halloween party it would take a very long time for me to describe what it is I'm doing here and then peoples' eyes would glaze over and they would walk away. Which is fine, I don't like talking to people at parties anyway so, forget about it.

Aside: Our eyes wouldn't glaze over because ant-decapitating flies are thrilling but the short version, according to Matt's writing is that a phorid fly pierces a host ant between the legs, launches an egg torpedo into its body and then it gets out of Dodge, it's like "Thanks, man," it lets the ant do the whole pregnancy part. The larva migrates to the ant's head, living off of its sweet, sweet juices before mind controlling it to leave the colony to more humid leaf litter and then pa-da! Off pops its head and like Marilyn out of a birthday cake, now you have another homicidal fly. Oh, the circle of life is so beautiful and brutal and disgusting.

Alie: Mikkel Max Jorn wants to know: Massospora and cicadas going bananas... What's up with that?

Matt: Flying saltshakers of death is I think what they're referring to. [*Alie laughs*] Cicadas get infected with this fungus. What this fungus does, it's not an intricate manipulator like *Ophiocordyceps* is but it just rots away the abdomen of the cicada to the point where you can have, you find cicadas kind of dragging themselves around missing basically the entirety of their abdomen that has just been eaten away. This one is fascinating because – this was not me who thought of the name flying saltshaker of death – but when it is flying through the air it's actually shedding those spores which then fall onto more cicadas, not unlike the way that *Ophiocordyceps* is operating. It's just not manipulating the behavior of the cicada as much.

Aside: Yes, we have a whole episode on cicadas, it's linked in the show notes and a highlight in my life was catching the emergence of Brood 10 in the Midwest a few years back. And cicadas, you can sing in my ear as loudly as you want even though I'm never going to mate with you.

Alie: Potato Puffer wants to know: What about the caterpillar that gets ants to be its zombie bodyguards by having it consume its secretions of dopamine that makes them less likely to move away from the caterpillar and more likely to be aggressive?

Matt: Yeah, it's a super cool one. There's a wasp that injects its eggs into caterpillars as well and they grow throughout its body and then erupt through the caterpillar's skin and the caterpillar doesn't die because as they're erupting, they're shedding parts of their skin that plug up the wounds and it keeps the caterpillar alive to act as a bodyguard as those little babies are developing. So, that's fun. But yeah, caterpillars actually have all those really cool interactions with ants in kind of terrifying ways. Do I have time for a really interesting one?

Alie: Yeah, bring it on.

Matt: Okay. There's this really lazily named species called the large blue butterfly. [*Alie laughs*] It is what it says on the tin. Its caterpillar does something even crazier; it lets itself get captured by ants that take it back into the colony, which would presumably turn it into food, right? But no. It also releases pheromones that trick those worker ants into thinking it is not only part of the colony but actually the queen. So, they dote on it; they take care of it, they feed the colony's actual larvae to this caterpillar that just goes to town on these things, tricking the ants into thinking that it's one of their own.

It gets even *crazier* because there's a hyperparasitoid wasp that comes into all of this and releases its own pheromones as it is entering the colony. This freaks out the workers, and they run around going absolutely bonkers. In the confusion, the wasp comes up to that caterpillar which had itself zombified the ants, injects it with its eggs, and leaves the nest. It's zombies all the way down, one after the other. But caterpillars, I love that question because they're so cute and cuddly and lovely, but they can be a little bit diabolical.

Alie: Rough.

Matt: Yeah, it's about grasping opportunities, right?

Alie: You gotta get your bag, you know?

Matt: Yeah.

Alie: Last listener question, let's end on a bummer. Robert G Audet and Caitlin Kalinowski wanted to know about global warming.

Aside: In Robert's words...

Alie: With the global temperature increase, there are signs fungi might be adapting to live at our slowly dropping body temperatures, now at 97.5 down from 98.6. (I didn't know that) Are we at risk for pathogenic brain-killing fungi like cordyceps as time goes on? Sheesh!

Matt: [*deep breath*] Great question. It's a heavy field within climate science, determining which pathogens we have to worry about more on a warming planet. So, where, for instance, will the conditions, warmer perhaps wetter, become better for fungi? Where are we going to get the expansion of malaria because mosquitoes are moving into new areas? It's a great question and not a bright topic but it's going to be super important for public health going forward. Not so much worrying about behaviorally manipulating parasites like these fungi that we've been talking about but certainly all manner of others that are going to expand their ranges due to climate change. I'm sorry, that's a bummer. I don't know how to phrase that in a... [*chuckles*]

Alie: Listen. There's no good way to phrase that large of bad news and if that doesn't get ya, might be the microplastics.

Aside: Again, his latest book about microplastics is called *A Poison Like No Other*, and it's linked in the show notes, just in case you'd like more info and terror in your life.

Alie: I'm just asking two bummer questions in a row but last the questions I always ask, usually I say what's the worst thing about your job. But I want to know what the suckiest zombie movie or something that bums you out about zombies or something that sucks about zombies or the worst artistic interpretation you've seen.

Matt: I think what bothers me most is just how they keep coming. Not unlike zombies, it's run its course, let's move on from zombies, let's maybe think of something... And this is coming from a person who wrote a book about zombies. [*Alie laughs*] I'm sick of hearing about them because also, I ruined it for myself because I feel like what has happened in nature, what has evolved many, many, many times, independently across the tree of life is so much more interesting than what some hacky screenwriter cobbled together in a coke-fueled afternoon. [*Alie laughs*] But that's just me being grumpy.

Alie: Favorite thing about writing the book? Favorite story or favorite experience traveling?

Matt: I think walking through New Mexico looking for the horsehair worms, the scientist walking me around, there was a sign that said, "Beware of bears and mountain lions" or something along those lines. He's like, "Don't worry about it, I've never seen a bear or a mountain lion out here." And I'm like, "Well, they put the sign up for some sort of reason." [*Alie laughs*] He was a good guy, I loved him, I gush about him in the book. But I'm not a hiker, I actually despise hiking. [*Alie laughs*] [*"I'm sorry, what?"*] But that was the best hike that I've ever been on because I got to hold a handful of horsehair worms and it's just like, I feel... This is a stupid word; I don't use the word 'blessed' ever but it's the best way I can think of saying it. I'm blessed to have a job that allows me to not only go do things like that but to go to work every day and learn from very smart people, as you do, people that are maybe two or three times smarter than me. It's a humbling experience but also, I get to learn every day and I love it, every minute of it.

Alie: Is there a reason you hate hiking? Just curious.

Matt: I don't... So, [*chuckles*] I understand it's stupid and I'm going to get dragged for this as well, [*Alie laughs*] but I just don't like that there's nothing at the end. I could walk 50 miles through a city if there's some cool destination like a bookstore, and then I'm totally fine walking all the way back. I don't understand walking up a mountain to see, like, a rock or a tree. [*"How dare you?"*] If you've seen one tree, you've seen all of them. I'm not saying the outdoors are bad, I'm just saying that the method of experiencing the outdoors by way of a hike is my less-than-favorite thing to do, in

addition to the predators out there. Don't forget about the bears and mountain lions. What if they eat you?

Alie: I'm fueled by snacks and that when you get to where you're going you stop and have a snack and then you go back. So, a lot of the time I'm thinking about whatever kind of trail mix with M&Ms and stuff we got.

Matt: I've never thought about it from the snack perspective but that makes sense. Maybe I should load up a backpack with good snacks.

Alie: Well, I wish you many years of indoor activities.

Matt: Thank you.

Alie: Please keep writing books because they're some of my favorites. You and Mary Roach are just killing the game out there.

Matt: Thank you.

Alie: Just writing such good stuff. So, I hope people pick up this one and if they're too happy about it get your microplastics book.

Matt: Yeah, want a sweet dose of reality? Buckle up.

Alie: [laughs] This has been a joy, thank you so much.

Matt: Likewise. I really appreciate it. Good talking as always.

So, ask smart authors unsmart questions and you're bound to stagger away with just a brain load of goodies. Thank you so much to my pal Matt Simon for obliging and telling me all about these critters. His book, *Plight of the Living Dead*, details even more and it's just such a fun read. His new book, *A Poison Like No Other* is linked in the show notes for you. There's also a link to the World Wildlife Fund.

We are @Ologies on Instagram and Twitter, I'm @AlieWard on both. *Smologies* are kid-friendly versions of classic episodes and they're linked in the show notes or up at AlieWard.com/Smologies. Thank you, Zeke Rodrigues Thomas and Jarrett Sleeper of Mindjam Media for editing those as well as Mercedes Maitland. Thanks to Erin Talbert for adminning the *Ologies* Podcast Facebook group. Emily White of The Wordary makes our professional transcripts. Susan Hale is our lord and managing director. Noel Dilworth is scheduling producer. Kelly R. Dwyer makes the website, and the puppeteer of our editing process is Mercedes Maitland of Maitland Audio. Nick Thorburn made the theme music.

If you stick around until the end of the episode, I tell you a secret and last week... Okay, okay... Buckle up. I was coming back from the East Coast on the plane with Jarrett and it had been a weirdly hellish travel day with this layover and a storm; the worst turbulence I've ever been in. We were sitting in the back row of the plane, right next to the toilet and we had our 10-year-old daughter, Gremmie, who is a delight and also a dog. And we were landing after this really long 12-hour airport day, and I went to wake Gremmie up under the seat... and her ear felt cold so I shook her and she didn't move or wake up. She hates her paws being touched so I was hunched over kind of touching her paws... Nothing. And I told Jarrett kind of in a panic, and he tried to wake her... And nothing. And he pulled her travel carrier out of the seat, and we were both on this plane screaming "Gremmie! Gremmie!" My whole life just changed because Gremmie had died, on a plane, while we

were sitting two feet away, totally unaware that she passed under our feet, and I almost threw up. Jarrett was about to start crying... And then her head popped up just like, "Hey guys! You got any cheese?"

I don't know how she was sleeping so soundly. We thought for a good minute she was dead. So, hug your loved ones because it's not often that they spontaneously resurrect from the seeming dead a week before Halloween. Anyway. Wheuf! Very lucky. Berbye.

Transcribed by Aveline Malek at TheWordary.com

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[Largest living organism](#)

[Microphallus hoffmanni](#)

[Parasitic manipulation and neuroinflammation: Evidence from the system *Microphallus papillorobustus* \(Trematoda\) - *Gammarus* \(Crustacea\)](#)

[Influence of *Microphallus hoffmanni* \(Trematoda, Microphallidae\) on the survival, sexual selection, and fecundity of *Gammarus aequicauda* \(Amphipoda\)](#)

[Sexual Selection, Natural Selection, and Body Size in *Gammarus pulex* \(Amphipoda\)](#)

[A Comparative Field Study of the Breeding Behaviour of a Stream and a Pond Population of *Gammarus Pulex* \(Amphipoda\)](#)

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[*Microphallus* Ward, 1901](#)

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