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R: Welcome to IFLScience The Big Questions. I'm Rachael Funnell, writer and producer for IFLScience, and I'll be your host. The impacts of the climate crisis are all around us, from an uptick in extreme weather events to the near extinction of animals like polar bears that can't tolerate the rapid rate of change. But what about the changes happening closer to home? For instance, what is climate change doing to our bodies? That question is tackled in *The Weight of Nature: How a Changing Climate Changes Our Minds, Brains and Bodies*. In it, author Clayton Aldern leans on his background in neuroscience to explore what the science has to say about the effects of a changing climate on our health, and what it could mean for future generations. So, we sat down with him to find out more.

I: So, hello Clayton Page Aldern, it's great to have you on The Big Questions.

R: It's great to be here.

I: And we were very excited when we came up with the idea that we wanted to talk to someone about whether or not climate change is having a visible impact on our health and it just so happens that you have written *The Weight of Nature, how a changing climate changes our minds, brains and bodies*. My immediate thought was that this was obviously a very timely topic but I was curious to know if there was anything specifically that motivated you to write this book now.

R: I've been working on the book for quite a while, something in the order of six or seven years and the genesis story there is I had recently left academic neuroscience for environmental journalism and my first editor in journalism said, hey well you're a neuroscientist, surely there is a series to be written on "this is your brain on climate change", or something to that extent, to which I basically promptly said no, because neuroscience is so readily sensationalised that I imagined that if there was any science there to twist it in such a manner that offered a connection between climate change and brain health was to not do integrity to the science. So, this man was my boss so I said yes and approached the initial line of questioning with a fair amount of scepticism. It was in that initial arguably healthily sceptical line of enquiry that some of these effects did begin to materialise for me in a manner that felt worthy of a certain urgency, felt worthy of a deeper dive and it has been over the past few years that I have taken the dive in question. So no, there is nothing about the moment in which we have found ourselves today, per se that I think warrants this text aside from the fact that these effects are very real and are only going to continue to become more real over the coming decades. I think the moment to have written this book would have been a decade ago, or two decades ago, but the science didn't exist then and we're only beginning to piece the puzzle together today, to

the extent that this book can be part of that puzzle piecing. I'm happy that it's coming out when it is.

I: Absolutely, and we will get into some of the specific examples that you mention later on. Just to start, at the start, I liked how you said in the opening pages about how the natural world tugs and prods at the decisions that we make each day. Could you just sort of elaborate on that point?

R: Sure. This is everything from the very small to the relatively large. On the smaller side of the house, think about the fact that when you get less sleep because its hot out, in the morning you may be more inclined toward a second cup of coffee, right, that's an example I offer at the beginning of the book. Its not that you aren't making a decision in that instant, however it is that there is an environmental factor that is forcing your hand a little bit. Had it been a temperate night, you wouldn't have perhaps reached for that second cup of caffeination in the morning, and so this is an interaction between an environmental force and a behaviour as manifest in a decision you make about how you're going to treat yourself throughout the day. That isn't particularly concerning and in fact it maybe doesn't even change the trajectory of your day too much. Certainly doesn't change the trajectory of your life, and yet, in terms of neurocognitive outcomes, in terms of behaviours that we do see arising more frequently perhaps as a function of a changing climate, some of these decisions that we make that are influenced by environmental fluxes do have a greater influence on our ultimate life trajectories. One example is the fact that students aren't as good at taking tests in the heat. We're not as good, as humans, at critical thinking, at executive function, at the higher order reasoning that's necessary to follow through on evolutionary promise of our brains. Pretty darn reliably, wherever you look at warmer level, at higher levels of heat, at higher levels of air pollution, higher levels of ambient carbon dioxide concentration, that kind of critical thinking capacity drops in kind. So, that's a neurocognitive outcome from an environmental exposure. It's also true that people are more aggressive in the heat. You have probably experienced this, I certainly have. On a hot day we're more prone to react to the world around us with aggression and indeed perhaps with violence and those effects which we have seen manifest basically everywhere we have looked, at the individual level, at the city level, at the country level, they add up. Those effects do matter and we can find them not just with respect to something like the instantaneous risk of civil conflict as geopolitical scientists will often phrase it, or climate economists might research. We see it in our day to day lives. We know, for example, that warmer days are predictive of more incidents of online hate speech or of indeed, instances of domestic violence or aggravated assault. We know that baseball pitchers are more likely to hit batters of the opposing team intentionally with their pitches on hotter days and in fact, are more likely to retaliate in this manner if a batter on their team has been hit by an opposing pitcher on a warm day. So it's not just that the heat influences the aggressive act in question, it also influences the retaliatory act. So, again, we may, as individuals not always be able to pinpoint the moment at which we are pushed over some threshold that results in a behavioural change but summed over the extent of a population and over time, these effects add up and they do matter, culturally and economically and with respect to the ways that we, as a society are preparing for the crisis in front of us.

I: I think it's an interesting one to think about, that in particular in terms of you can look at the effect on a large scale but also to an individual you can see how that might impact things like relationships and your capacity to get on with those around you, made even harder just by the changing climate.

R: Yes. And again, we have dozens of examples of how interpersonal relationships are influenced by something like heat or something like air pollution. Our complexity of speech, for example, tends to decrease as a function of rising air pollution. You have this fabulous study that came out of the University of Ottawa that shows that the complexity of Canadian parliamentarians, our members of parliament, the complexity of their speeches decreases as a function of ambient particulate matter levels. We know that immigration judges are less likely to rule in favour of asylum applicants on hot days and this is not relative to those judges in cooler climates, this is relative to past decisions that judges themselves have made. So this is an individual relationship between heat and cognitive processing, heat and perhaps compassion, heat and the ability to hear the facts of a given case. These are all interpersonal connections. What is more interpersonal than a decision that one might make about the future of another person's life? So certainly, we are seeing the effects play out, not just within our own heads but in the manners in which we relate to one another.

I: And so, if we talk about the things that are going on inside our own heads, what's one of the most dramatic examples you came across of how environmental stresses can impact our neurological well-being?

R: There are so many, unfortunately, dramatic examples. One that comes to mind is evidence that has recently emerged from a decades long longitudinal study out of New York that consisted of a cohort of hundreds of expecting mothers who had been assembled by a researcher interested in the relationship between stress, as broadly defined, and maternal child health outcomes in pregnant women and their offspring. In 2009, this researcher, Yoko Nomura, assembled the cohort in question, it was about 400 expectant mothers and began to track their various environmental exposures, which aren't just climatic in nature. We're talking about the entire environmental and socioeconomic set of conditions that define somebody's experience. Everything from the crime rate of a given neighbourhood to light and noise pollution, are commonly measured in studies like these those I don't know if Nomura did in hers. All of these kinds of potential environmental factors that influence this notion of stress and the extent of which these stressors may be predictive later in life for the children in question in terms of any kind of neuropsychiatric outcome that they experience. So this was 2009. 2012 rolls around and hurricane Sandy comes to town. This is an extremely severe superstorm, as it were. Dr Nomura realises that she has a natural experiment in front of here wherein you have a series of expecting mothers who are carrying children while the storm is rolling into town and you also have a set of folks who have either given birth prior to the storm or indeed conceived after it, because she was always recruiting new folks into the study. So she splits her study into two separate cohorts, those who in terms of the children in question experienced Sandy in utero and those who did not, but experienced many of the other environmental stressors in question and she runs all the statistical corrections to ensure that we're adjusting for these various exposures and wants to isolate the effect of exposure to the storm. In 2022, ten years into the lives of these children she looks back and asks, what are the neuropsychiatric outcomes for the

kids who have been exposed to Sandy in utero versus those who weren't. What she finds is that as early as pre-school, the children who were exposed to the storm are presenting with symptomology representative of anxiety, depression, OCD, conduct disorders, ADHD, at far higher rates. We're talking 2x, 3x, 10x the rates of those who were not exposed to the storm and if you break the results down by gender, in fact, they're even more concerning. We're seeing boys expressing these conduct disorders or ADHD for example, anywhere from 30x to 60x the rates of young boys who are not exposed to the storm. Girls expressing anxiety and depression at rates 10x to 30x the rates of whose who were not exposed to the storm. So, this is an example of a climatic influence on the unborn who had nothing to do with the climate whatsoever, who had nothing to do with that climatic influence, other than exist in utero. But hormonal expression on behalf of the mother, these glucocorticoid responses, molecules like cortisol, they cross the placenta. These are molecules that ideally inform the stress profile of an infant, right of foetus and then of an infant, in a protective manner. We do need to be exposed to stress of some flavour because if we aren't exposed to a little bit of cortisol, to a little bit of these other stress hormones, we're going to have maladaptive stress responses later in life. We're not going to know what to do when we're stressed as children. But what Dr Nomura would say is that everybody has a breaking point and if you experience such an extreme stressor such as something like a hurricane or a wildfire, the cortisol storms in question that you as a foetus are receiving in utero, they're enough to affect epigenetic changes on your genome. They are enough to affect degrees to which protein expression, for example, may occur in your developing brain or modify these neurodevelopmental milestones that you're supposed to hit and when you hit them. The result of these epigenetic changes, which, by the way are in turn inheritable in the next generation, are in fact the neuropsychiatric disparities that we observe in studies like hers. So, that's an example of something that I find deeply concerning that you don't even need to be alive yet to have these neuropsychiatric harms seeded within you.

I: And as you said that's so far based on observation of ten years but with epigenetics we do sometimes see that things don't really emerge until later in life so is it possible we could see further affects from having been in utero during these storms?

R: Almost certainly, and it's also the case that in the field of research that concerns the relationship between neurotoxin exposure and neurodegeneration as a function of environmental change, one example there is cyanobacteria, blue-green algae, appear to be releasing a neurotoxin that is a primary causal predictor of the risk of something like ALS or Lou Gehrig disease, motor neurone disease, when we look at fields like those that relate neurotoxin exposure to neurodegeneration we don't see diseases manifest immediately. That's not how neurodegeneration works, you don't, you know, take a whiff of a cyanobacterial cloud and all of a sudden come down with ALS the next day because the etiology of these diseases is defined by a series of discrete exposures that you experience over time and these exposures are interacting with your unique genetics and ultimately over the course of 20 years, 30 years, 40 years, ultimately result in the presentation of a disease. Yet, the initial step, the initial box that you check, it may have occurred in childhood, who knows? And this is a bit speculative, maybe it occurred before childhood right? Maybe it occurred in utero. What we do know is that the relationship between environmental stressors and neurocognitive outcomes and our psychiatric outcomes, neurodegenerative outcomes, it's so dispersed and so widespread and frequently so

chronic that it's exceptionally difficult to predict the relationship between a single exposure and a given outcome later in life. All we know is that these are risk factors and at some point there is a straw that breaks the camel's back.

I: So you talk there about the kind of neurological diseases side of things but there is also going to be psychological impact of things like experiencing an extreme weather event. So have we seen ways in which that has affected people as these kind of weather events become more common?

R: Yes. You don't need to go to war to suffer from post-traumatic stress disorder for example. The violence of a hurricane or a wildfire will do the trick. We were mostly just speaking about the neuropsychiatric health outcomes of the children who experienced something like a hurricane in utero. The mothers in question walk away with PTSD. If you look at low-income parents who experienced Hurricane Katrina in New Orleans, half of folks exhibit post traumatic stress symptomology. There is a researcher in California who looked at the degree to which something like post-traumatic stress was evident in people who lived through what was known as the camp fire, this was a huge wild fire in the year of, gosh, 2020 or 2021, and what we know about this particular wild fire that is probably true of other climatic stressors is that one's proximity to the stressor itself, the degree to which you were directly versus indirectly versus not at all exposed to that fire, is predictive of the severity of your neuropsychiatric outcomes along these post-traumatic stress lines. So, if you lost property or a family member, if you were directly impacted by the fire your rate of PTSD is about 3x that of those who were indirectly impacted by the fire, such as knowing somebody who lost property or perhaps needing to evacuate but the fire didn't actually touch your house, that kind of thing. And yet even those with indirect exposure to wildfire experience PTSD at a rate 3x those who didn't come into contact with the fire in any capacity whatsoever. Now, what do we know psychologically about the outcomes of the folks who do experience some form of post-traumatic stress as a function of climatic stressors? This same researcher, Jyoti Mishra in California, looked at neurocognitive outcomes among the climate stressed, among those who have effectively contracted PTSD via a wild fire exposure, looked at the cognitive outcomes and asked what is it in particular that is being inhibited in these people when they are asked to navigate their lives, solve problems, make decisions, and what she finds is that the process that appears to be most specifically affected is ones ability to ignore distractors in the environment. The people who are the most stressed post trauma because of climate trauma effectively start to look almost as if there is some kind of ADHD going on. They're much more distractable than other people and indeed than other people with other flavours of indirect climate trauma exposure. So here we are talking about a very specific neurocognitive outcome that with direct exposure to climate trauma comes both post-traumatic stress and a specific deficiency in terms of one's ability to navigate distraction in the world around them. So, when I read research like that, I think about the question you've just asked. How is climate stress, how are climate stressors, climate trauma bearing… how are these things bearing directly on our psychology via the neurological route? How are they bearing on our behaviour, our decision making? I think these effects are beginning to be well characterised and quite specific. We're not just talking in this conversation about "climate anxiety", which is very real, but climate concern is a totally different field than

what we're discussing right now. Right now we're talking about the direct affects of environmental flux on brain health.

I: These kinds of outcomes, when it's the result of psychological trauma, are they random? To my mind it almost seems like to go through something first hand that horrific and then to be more easily distracted, could that be seen as an almost protective way of trying to look out for signs or something similar might be coming, or is it simply just one of the way in which we see people affected neurologically by such events?

R: It's a great question. When people in New Zealand experienced the earthquake that struck one of the islands a few years ago, a handful of neurologists began to study the people in question and found that upon such an experience, in their recovery they developed a totally different spatial awareness, that spatial processing, modes of navigation had shifted and one could argue with enhanced spatial cognition, a brain is responding to something like a dramatic re-mapping of one's environment, an adaptable re-mapping of ones environment that an earthquake represents. We also know that a classic study of neuroscience, London cab drivers have… I think what is the finding, larger hippocampi in their brains. This is the memory centre of the brain but in particular the region that is enlarged within taxi drivers here is that which is responsible for spatial cognition. We develop such spatial cognition, such enhancements through our interactions with the environment. It's no surprise that taxi drivers have these adjustments because that is the part of their brain that they are working all the time. So, might something like distractibility response to climate trauma be adaptive, I think is a fabulous question. I think for me, the answer which is a little bit speculative because I'm not sure we have the answer per se, would suggest its an attempt on behalf of the brain to be adaptive and ultimately an overcorrection because we do want to attend to relevant threats in our environment. The problem is if everything in front of our eyes is deemed relevant we're going to perceive all of those things as threats. So distractibility as it relates to the perception of future threat can represent a huge problem insofar as opposed to what's called the brain's salience network as opposed to the salience network being appropriate attuned to environment threat, you've cranked it up to such a degree that it thinks everything around you is a potentially relevant stressor, a potentially relevant threat. So that would represent a maladaptive response. I'll just add one more bit here which is to say I do think that we have some evidence that suggests some of the neurological changes that we observe in, for example, the most climate concerned among us do represent adaptations to a future world that we are likely to encounter. By way of example, a study from last week or the week before that attempted to understand the neurological differences, structural and functional, between those with higher climate concern and lower climate concern and correcting for base traits of anxiety, so this is not a study about general anxiety disorder, it corrects for that and instead just compares the most climate anxious to the climate concerned but not as extreme. What the study finds is that among the most climate concerned you see a smaller region of the brain, called the mid singular cortex, this region is smaller in these folks. The mid singular cortex is basically responsible for sensing and responding to future threats of uncertain value. So, okay that sounds an awful lot like climate change, makes sense if there a relationship there, why is it smaller? The other finding in this study is that the smaller mid singular cortices that you find in people with climate concern, they're actually more densely connected to… there's higher

functional connectivity between those cortices and the salience network that I mentioned earlier. What that would seem to imply is that you basically among those who are most cognitively and emotionally impacted by the climate crisis, you see more efficient wiring in this region that is responsible for responding to future uncertain threat and it is perhaps, in fact, that type of wiring efficiency that affords a certain paying attention to the future that is going to matter for climate action. We do have one bit of evidence that suggests that it does in fact matter for climate action because those same people, the ones with the most climate concern along that kind of cognitive emotional axis, they are also the people who are most likely to engage in pro-environmental behaviour. So, maybe is my short answer following a very long answer to a short question of yours, maybe some of the changes that we're witnessing in the brains of people who are exposed to climate change, which is to say, most of us, perhaps all of us, some of those changes might be adaptive, yes.

I: It's incredible to hear the things that we have been able to glean over the course of this because one thing that struck me when you were talking about the research earlier is how long you have to be looking at this stuff for and how much data is required to be able to draw effect. So, where is it that people are getting the information from and do you think we are going to be finding out more and more as we've been living through this crisis for a longer length of time?

R: Yeah. I mean, it's really hard to run these types of studies because you can't selectively expose expecting mothers to a hurricane, right? A, for ethical reasons, but B, because we can't just gen up a hurricane and be like, okay great, we've got our experiment, now let's run it. So, many times at the population level we have to rely on these natural experiments, so we're left waiting around for a while. That said, we can plan carefully and we can also seek to integrate findings and indeed datasets from disparate fields that are already sitting around. A great example comes from Finland, for example, in which there recently was a study that sought to understand the relationship between heat, temperature, a certain biomarker of the serotonergic system, a protein level related to serotonintransmission that can be measured in the blood and rates of violent crime in the country. The researchers, these neurologists believed that there may be serotonergic pathway by which higher temperatures were predictive of violence. What they actually did to run the study was basically take some data off the shelf that already existed because there was a study that had been run a decade prior that compared the biomarker in question among violent offenders, folks who had been incarcerated for violent crime, to those who had been, I believe, incarcerated for non-violent crimes and indeed perhaps relative to folks who hadn't been incarcerated at all. What they find is that amongst violent offenders not only was the relationship between temperature and the serotonergic biomarker the strongest, but also in that group if you took a look at time varying measurements of the biomarker in question and compared it to the violent crime rate in Finland, you could explain 40% of the variance of the country's violent crime rate over this two-decade period or so. So, this is an example of researchers being able to take stuff of the shelf and run what would otherwise be a very difficult prospective study. Instead they can look historically and grab weather data which are pretty easy to download, and in their case grab some existing biomarker data and demographic and socioeconomic and indeed crime related data, all of which had been conducted by previous researchers, collected by previous researchers and then stack these

things on top of one another and ask a very important question very quickly. So, I think looking forward, if we can, as a research community, as an interdisciplinary research community, come to be a bit more creative in the manners in which we are assembling these interdisciplinary datasets, I think that we will expect to find more of these results tumble out of those analyses more frequently.

I: As we move forward and more information does become available, what changes would you like to see in how we approach the impact of climate change environmental stressors on human health?

R: First of all we need to be paying attention to this stuff in the first place. From a policy making perspective, climate policy runs on cost benefit analysis. In order to invest in climate action as a government you be able to need to justify that investment, you need to say the dollars we're going to spend on this thing outweigh the costs and the public costs of this crisis, the benefits afforded to us by this investment outweigh the societal costs that are accruing by making the investment. So it's great that public health, for example, is beginning to be integrated into our climate policy. We have mortality estimates as a function of climate change, morbidity estimates as a function of climate change but most of those estimates rely on an understanding of the relationships between climate and health that's predicated on malaria, respiratory diseases, cardiovascular health. There's nothing in any of these models that include neurological health and I think if we are ignoring the neurological costs of the climate crisis, we are effectively missing a piece of the pie because of that cost benefit equation it makes climate action harder to justify. If it costs $100 to build a solar panel and you're arguing that the health costs of climate change are worth $80 dollars of offset then you still can't quite justify that investment and yet if you were to integrate neurological costs and perhaps make up the additional $20, lo and behold, all of a sudden you're breaking even on this investment because you've offset more health costs. So, I think its essential that societally we are including the neurological costs in question and in our analysis and that includes everything from the cost of care for neurodegeneration, it includes the burden of disease when we talk about brain diseases like cerebral malaria, and dengue, and yellow fever, all the stuff that is spreading as a function of the increased habitable range of ticks and mosquitos, various protozoa that are responsible for some of these brain diseases and it also includes some of the stuff we have talked about today like the fact that productivity decreases as a function of rising temperatures, aggression increases. There is a societal and also economic cost of violence in a given community, in a given economy and if we're turning a blind eye to these effects and failing to integrate them into our climate modelling, into our climate health modelling then I think we're doing a disservice to the act of designing climate solutions 'cause they're harder to justify.

I: Yeah, I think that's a great point and it's really interesting to read across your book, as someone who hasn't studied this, to be introduced to the idea of neurological costs of climate change and the many different ways they can appear and behave. Just to finish on, I'd like to know what is it that you hope others will take away from this book and on the kind of individual scale?

R: We have spoken about some scary stuff over the course of this conversation. I don't want people to take away fear and I don't think we have to. I think that some of the effects that

we're describing are profound and indeed when considered in isolation could inspire fear but I don't think that the takeaway. The fact, to me, that the environment is so capable of crossing this boundary between world and self, the fact that our skin, our separation between internal and external is so porous that the environment can just reach in and influence our cognition, behaviour, decision-making, neurological health, that to me is a suggestion that it really is kind of funny that we consider a self to be somewhat separate at all from the rest of the world and with that shift of reference frame, with the notion that there is no separate self, that we are all part of… this is the kind of classic "we're all connected" etc etc… the neuroscience of climate change I think undergirds an understanding of that common expression that makes it much more real to me. What can you do with that realness, what can you do with interconnectedness and the porousness of the self? I think that you can reach out in the other direction. It is at once true that the environment is reaching in and influencing your internal biophysics and neurochemistry and psychology. It's just as true that our actions matter, our reaching out into the environment matters just as much and I think that's where we can start to recapture agency. So much of this conversation for me often boils down to, well gosh, if the environment is forcing our hands in these manners what does that mean for free will? I guess we don't have as much of it as we thought and yet, I think our understanding of the issues in question affords a certain recapturing of agency, affords a certain recapturing of free will that says, no, the porousness of ourselves suggests that our actions matter and we get to choose, therefore, what we do with those actions. We can still choose compassion, we can still choose mutuality and protest and in indeed, I don't know, cost benefit analysis. But most fundamentally we can choose a certain collectivity, a certain community approach that implies we are not alone in this fight and instead that community notion, the relationship between people in collaboration with, as part of this dance with our environment, that is what ultimately will result in a societal response to the crisis.

I: I think that's a really beautiful way of putting and I can see why you have made it as a writer. Thank you so much for that introduction into the neurological costs of climate change. It's been great to have you on.

R: It's been great to be here, thanks so much.

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