Life Ascending

The Ten Great Inventions of Evolution

Chapter 8: Hot Blood

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About

Dr Nick Lane is a British biochemist and writer. He was awarded the first Provost's Venture Research Prize in the Department of Genetics, Evolution and Environment at **University College London**, where he is now a Reader in Evolutionary Biochemistry. Dr Lane's research deals with evolutionary biochemistry and bioenergetics, focusing on the origin of life and the evolution of complex cells. Dr Lane was a founding member of the UCL Consortium for Mitochondrial Research, and is leading the UCL Research Frontiers Origins of Life programme. He was awarded the 2011 BMC Research Award for Genetics, Genomics, Bioinformatics and Evolution, and the 2015 Biochemical Society Award for his sustained and diverse contribution to the molecular life sciences and the public understanding of science.

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Time flies by when you're the driver of a train, runs a children's lyric. And who can't remember the reverse as a child – the endless minutes of mind-numbing tedium in the back of a car, asking repeatedly, 'Are we there yet, Daddy?' I imagine most readers will also remember the distress of watching their ageing grandparents, or parents, slow down to a snail's pace, in the end sitting inscrutably as hours pass by like minutes. Both extremes are far removed from the tempo of our own world, the andante of an adult human being.

We don't need Einstein to tell us that time is relative. But what Einstein established rigorously for time and space is, as ever, more impressionistic in biology. As the celebrated wag Clement Freud had it: 'If you resolve to give up smoking, drinking and loving, you don't actually live longer, it just seems longer.' Yet there is a real sense in which time rushes through childhood, and crawls through old age. It lies in our internal settings, our metabolic rate, the rate at which our hearts beat and our cells burn up food in oxygen. And even among adults there are striking differences between the active and the slovenly. Most of us shift slowly from one to the other. The rate at which we slow down, or indeed gain weight, depends much on our metabolic rate, which varies innately between individuals. Two people who eat the same and exercise equally will often differ in their tendency to burn off calories while at rest.

Nowhere is metabolic rate more significant than the difference between hot-blooded and cold-blooded creatures. While these terms make biologists cringe, they are vivid and meaningful to almost everyone, and convey as much as the slippery technical terms, like homeothermy and poikilothermy. It's a curious thing, but I've noticed there are few aspects of biology that we feel so chauvinistic about, we hot-bloods. The fury and spleen vented in journals, and online, about whether dinosaurs, for example, were hot-blooded or cold-blooded is hard to understand rationally: it is a visceral distinction, perhaps something to do with our dignity, whether we would rather be eaten by giant lizards, or clever, scheming, fast-moving beasts, against whom we must pit our wits to survive. We mammals still bear a grudge, it seems, for the time we spent as small furry animals, cowering underground in hock to the top predators of the past. But then it was for 120 million years, which is a long time by any reckoning.

Hot blood is all about metabolic rate, all about the pace of life. Hot blood helps in its own right, for all chemical reactions speed up with rising temperature, including the biochemical reactions that underpin life. Over the small range of biologically meaningful temperatures, from around 0°C up to 40°C in animals, the difference in performance is striking. Oxygen consumption, for example, doubles with every 10°C rise in temperature in this range, corresponding to mounting stamina and power. So an animal at 37°C has twice the power of one at 27°C, and quadruple the power of an animal at 17°C.

But to a large extent, temperature misses the point. Hot-blooded animals are not necessarily any hotter than cold-blooded animals, for most reptiles are adept at absorbing the energy of the sun, warming their core body temperature up to levels similar to mammals and birds. Certainly, they don't maintain such high temperatures after dark; but then mammals and birds are often inactive at night too. They might as well save energy by lowering their core body temperature, but rarely do, at least not by much (although hummingbirds often pass into a coma to conserve energy). In our energy-conscious times, mammals ought to make environmentalists weep: our thermostat is jammed at 37°C, twenty-four hours a day, seven days a week, regardless of need. And forget alternative energy. We 're in no way solar-powered, like lizards, but generate heat prodigiously by way of internal carbon-burning power stations, giving us a giant carbon footprint too. Mammals are the original eco-hooligans.

You might think that running on full power through the night would give mammals a head start in the morning, but lizards don't waste much time raising their temperatures back to operational levels. The earless lizard, for example, has a blood sinus on top of its head, through which it can warm its whole body rapidly. In the morning, it pokes its head out of its burrow, keeping a wary eye out for predators, ready to duck back in if necessary, and after half an hour is usually warm enough to venture out. It's a pleasant way to start the day. Characteristically, natural selection is not content with only one function. If caught out, some lizards have a connection from the sinus to their eyelids, through which they can squirt blood at predators, such as dogs, which find the taste repugnant.

Size is another way to maintain high temperatures. You don't need to be a great white hunter to picture the hides of two animals stretched out as rugs on the floor. Imagine that one such hide is twice the length and breadth of the other. This means that the larger animal had four times more hide than the smaller beast (2 x 2 = 4), but it would have been eight times heavier, as it also had twice the depth (2 x 2 × 2 = 8). Thus every doubling of dimensions halves the surface-to-weight ratio (4 / 8 = 0.5). Assuming that each pound in weight generates the same amount of heat, larger animals have more pounds and so generate more internal heat. At the same time, they lose heat more slowly because their skin surface is relatively small (in relation to internal heat generated). So, the bigger the animal, the hotter it gets. At some point, cold-blooded creatures become hot-blooded. Large alligators, for example, are technically cold-blooded, but retain heat long enough to be borderline hot-blooded. Even overnight, their core temperature only drops a few degrees, despite producing little internal heat.

Plainly many dinosaurs would have surpassed this size threshold comfortably, making them de facto hot-blooded, especially given the pleasantly warm ambient temperatures enjoyed by much of the planet in those halcyon days. There were no ice caps, then, for example, and atmospheric carbon dioxide levels were as much as tenfold higher than today. In other words, some simple physical principles mean that many dinosaurs would have been hot-blooded, regardless of their metabolic status. The giant herbivores may well have had more trouble losing heat than gaining it; and some anatomical curiosities, like the great armoured plates of the stegosaurus, may have played a second role in heat dissemination, not unlike an elephant's ears.

But if it were as simple as that, there would have been no controversy about whether or not the dinosaurs were hot-blooded. In this limited sense they certainly were, or at least many of them were. For those who like mouthfilling terms, it's called 'inertial endothermy'. Not only did they maintain a high internal temperature, they generated heat internally, in the same way as modern mammals, through burning carbon. So in what broader sense were dinosaurs not hot-blooded? Well, some of them may well have been, as we'll see later, but to understand the real oddity of mammalian or avian hot blood we need to reverse the size trend to see what happens in smaller animals, below the 'hot-blood threshold'.

Think of a lizard. By definition, it is cold-blooded, which is to say, it can't maintain its internal body temperature overnight. While a large crocodile might come close, the smaller the animal, the harder it gets. Insulation, like fur or feathers, only helps to a point and can actually interfere with heat absorption from the surroundings. Dress up a lizard in a fur coat (and needless to say, earnest researchers have done exactly this) and the lizard gets steadily colder, unable to absorb the sun's heat so well, or to generate enough heat internally to compensate. This is far from the case with mammals or birds, and that brings us to the real definition of hot blood.

Mammals and birds generate up to ten or fifteen times as much internal heat as a similarly sized lizard. They do so regardless of circumstances. Place a lizard and a mammal in suffocating heat and the mammal will continue to generate ten times as much internal heat, to its own detriment. It will have to go out of its way to cool down – drink water, plunge into a bath, pant, find shade, fan itself, drink cocktails, or switch on the air-conditioning. The lizard will just enjoy it. It's not surprising that lizards, and reptiles in general, fare much better in the desert.

Now try placing the lizard and the mammal in cold conditions, let's say close to freezing, and the lizard will bury itself in leaves, curl up and go to sleep. To be fair, many small mammals would do that too, but that's not our default setting. Quite the contrary. Under such conditions, we just burn up even more food. The cost of living for a mammal in the cold is a hundred times that of a lizard. Even in temperate conditions, say around 20°C, a pleasant spring day in much of Europe, the gap is huge, around thirtyfold. To support such a prodigious metabolic rate, the mammal must burn up thirty times more food than a reptile. It must eat as much in a single day, every single day, as a lizard eats in a whole month. Given that there 's no such thing as a free lunch, that's a pretty serious cost.

So there it is: the cost of being a mammal or a bird starts at around ten times the cost of being a lizard and is often far higher. What do we get for our expensive lifestyle? The obvious answer is niche expansion. While hot blood may not pay in the desert, it enables nocturnal foraging, or an active existence over winter in temperate climates, both of which are denied to lizards. Another advantage is brainpower, although it's hard to see why there should be a necessary relationship. Mammals certainly have far larger brains, relative to their body size, than reptiles. While a large brain is no guarantee of intelligence, or even quick wits, it does seem to be the case that a faster metabolism supports a bigger brain, without specifically dedicating resources to it. So if lizards and mammals both earmark, say, 3 per cent of their resources to the brain, but mammals have at their disposal ten times the resources, they can afford ten times more brain, and usually have exactly that. Having said that, primates, and especially humans, allocate a far greater proportion of their resources to brainpower. Humans, for example, dedicate around 20 per cent of resources to the brain, even though it takes up only a few per cent of our body. I suspect, then, that brainpower is little more than an added extra, thrown in at no extra cost, for a hot-blooded lifestyle. There are far cheaper ways of building bigger brains.

In short, niche expansion, nocturnal activity and added brainpower don't seem much payback for the serious metabolic costs of hot blood. Something seems to be missing. On the debit side, the costs of eating, eating, eating go well beyond bellyache. There is the serious cost of time and effort spent foraging, hunting or cropping vegetation, time vulnerable to predators or competitors. Food runs out, or becomes scarce. Plainly, the faster you eat, the faster you will run out of food. Your population shrinks. As a rule of thumb metabolic rate governs population size, and reptiles often outnumber mammals by ten to one. By the same token, mammals have fewer offspring (though they can dedicate more resources to the few they have). Even lifespan varies with metabolic rate. Clement Freud was right about people but wrong about reptiles. They may live slow and boring lives, but they do live longer, in the case of giant tortoises for hundreds of years.

So hot blood exacts a cruel toll. It spells a short life, spent eating dangerously. It depresses the population size and the number of offspring, two factors that should be penalised ruthlessly by natural selection. In recompense we have the boon of staying up at night and hanging out in the cold. That seems a poor deal, especially if we go to sleep anyway. Yet in the great pantheon of life, we routinely give top billing to the mammals and birds. What exactly is it that we have but the reptiles don't? It had better be good.

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