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OUTSIDE JEB

Angry birds: a hormonal link between hunger and hostility

Ever fought over the last piece of pie? Aggressive competition is common among animals, and hormones play a major role in such behavior. One of these hormones is testosterone, which is produced by the testes and directly interacts with brain regions involved in social interactions. The brain can also convert testosterone into estradiol, another hormone that is a key regulator of male aggression. Hungry animals can be especially aggressive over food, but it is not known which hormones regulate food-related aggression. Testosterone from the testes is not likely to be involved because fasting is stressful and stress suppresses testosterone production by the testes. A testosterone precursor – called dehydroepiandrosterone (DHEA) – could regulate food-related aggression because fasting increases its levels and the brain can convert DHEA to testosterone and estradiol. In Kiran Soma's lab at the University of British Columbia, Canada, postdoctoral researcher H. Bobby Fokidis is using social songbirds to investigate whether DHEA is the molecular link between fighting and food.

Fokidis and his colleagues decided to stage a bird food fight in the lab. First, the team housed adult male zebra finches in groups of two to four birds for 6 h with full access to food (fed), an empty food dish (fasted) or 6 h with an empty food dish followed by 15 min with full access to food (re-fed). Then, they removed all of the food dishes and all of the birds were offered food from a point-source feeder that only allowed one bird at a time to perch and access food. The team then filmed the birds to see how much jostling went on at the feeder, and measured the birds' levels of testosterone, DHEA and estradiol to find out which of these hormones was controlling the food fight.

The team found that the energetic zebra finch does not like to go without food. Compared with the fed group, the fasted group was more aggressive when the point-source feeder was introduced, and frequently chased and displaced other birds in their group. Aggression in the re-fed group was intermediate between that of the fed and fasted groups, showing that food status was directly involved in these behaviors.

Next, the team looked at how hormone levels compared between the three treatment groups. They found that testosterone was lower in blood taken from the brachial veins of birds that were fasted for 6 h, even if they were then re-fed. Blood in the brachial vein has not been to the brain yet, so any hormones found here were made in peripheral organs. Therefore, the team ruled out testosterone made in the testes as the hormone responsible for turning the feathered friends into foes. When the team measured DHEA levels in the brachial vein, they found that it was higher in the fasted group than in either the fed or re-fed groups, and when the team checked the two organs that produce it – the liver and adrenal glands – they found higher DHEA there too. However, the team found no differences in DHEA levels in blood taken from the jugular veins of birds in any of the treatment groups. Because blood in the jugular vein has just left the brain, the team thought that the extra DHEA made by the liver and adrenal glands of the fasted birds must have been converted to another hormone by the brain. In fact, Fokidis and his colleagues found more estradiol, which can be made from DHEA, in several brain regions that mediate social aggression in both the fasted and re-fed birds compared with the fed birds.

So, this study shows that DHEA may mediate food-related aggression after it is converted to estradiol in neural circuits that regulate social interactions, and drives who gets the last crumb in a zebra finch food fight.

10.1242/jeb.094680

Fokidis, H. B., Prior, N. H. and Soma, K. K. (2013). Fasting increases aggression and differentially modulates local and systemic steroid levels in male zebra finches. *Endocrinol.* **154**, 4328-4339.

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Insect gears give great jumps

We humans think that we are pretty smart. We have invented a dizzying array of machines and mechanisms that have transformed the way we interact with the world. Yet despite all our cleverness, the products of evolution can still outdo us – sometimes by millions of years.

In a recent issue of *Science*, Malcolm Burrows and Gregory Sutton of the University of Cambridge reported that the nymphs of *Issus coleoptratus*, a common species of planthopper (a type of true bug), have the first known case of an evolved working gear mechanism. Noticing that planthoppers have legs arranged under their bodies that rotate in the same plane, they reasoned that the nymphs must synchronize their back legs somehow to allow them to jump without spinning out of control, but what mechanism could the animals be using?

To get a better handle on how planthoppers hopped, the duo first used a high-speed camera that captured 5000

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images per second to film the tiny creatures. They found that *I. coleoptratus* was able to begin hopping within 2 ms of stimulus, and was able to synchronize its two back legs within 30 μs of each other – a feat that would be nearly impossible by nerve transmission (which takes sluggish milliseconds).

To take a closer look at what *I. coleoptratus* did when it jumped, Burrows and Sutton mounted individual planthoppers upside down in Plasticine while they filmed the insects' undersides at 30,000 frames s^{-1} and watched the action of the legs. They found that the trochanters (the second joint on an insect leg moving out from the body) of the two back legs each had a strip of gear teeth located on their inner surface. When the planthoppers prepared to jump, they rotated their rear legs, which rotated the two cogs at the top of the femur so that the teeth of the gears meshed together as the legs prepared for launch. Then, when the planthoppers jumped, the legs snapped forward with the gear teeth re-engaging as the legs rotated in the opposite direction, to synchronize the movement of both limbs for a successful launch.

The researchers used a scanning electron microscope to look at the fine-scale structure of the insect cogs. They found that each tooth on the gear was tiny – only 15–30 μm high – and separated from the next tooth by another 30 μm. Strangely, once *I. coleoptratus* moults into an adult, it loses the gears. They hypothesise that this might be because adults do not moult and so are unable to repair the teeth if any were to become damaged.

Burrows and Sutton think that without the gears, jumping *I. coleoptratus* nymphs would not be able to synchronize their legs in their fast jumps. Understanding how such tiny gear mechanisms work could help engineers develop small machines. It seems that insects have still got the jump on us – in this case, literally.

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Burrows, M. and Sutton, G. (2013). Interacting gears synchronize propulsive leg movements in a jumping insect. *Science* **341**, 1254-1256.

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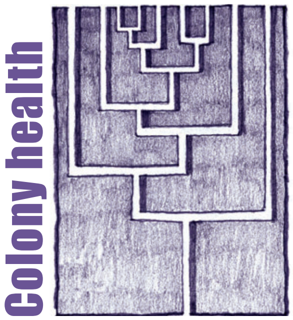
Faecal pharmaceuticals and external immunity in termites



Formosan subterranean termites are among the most socially sophisticated of animals. Living in underground colonies millions strong, these insects share the work of foraging and defence while jointly benefiting from the fruits of their labours. However, with the advantages of social life come certain challenges. For a start, there is the problem of disease risk in a colony comprised mainly of siblings. And then, what do so many termites do with all of their waste? A recent report published in the *Proceedings of the Royal Society, Series B*, describes a novel integration of sanitation and public health that allows termites to tackle these problems together.

Colonies of Formosan termites are like vast underground cities. Tunnels that termites travel in search of food extend for hundreds of feet through the soil. These emerge into hollowed trees, buildings and homes, where termites construct dwellings called 'carton nests' composed of chewed wood, saliva and termite faeces. Unsurprisingly, these nests are not only comfortable homes for termites. A group of scientists led by Thomas Chouvenc at the University of Florida in Fort Lauderdale, USA, discovered that nests also support the growth of bacteria and fungi. However, pathogenic fungi are notably absent from the carton nests. This is a good thing for termites, of course, but how are the nasty fungi kept at bay?

When the researchers tested whether the nest itself was antifungal, this proved not to be the case. Fungal pathogens inoculated into a growth medium made from termite cartons – appealingly called termite faecal agar – grew rapidly and reached high densities. By contrast, when the faecal agar was co-innoculated with a particular bacterial species isolated from the carton nests, fungal growth was arrested. Looking further, the team found that this same bacterial species, a type of filamentous bacterium called a streptomycete, secreted compounds that directly inhibited fungal growth.

Several studies over the past decade have published similar results in a broad range of insect species: an insect is squashed, a streptomycete is isolated from the corpse and this bacterium is found to retard growth of a pathogen that would attack this insect in an *in vitro* assay. The story usually ends here, with the inference that the streptomycete derived from the insect somehow aids the species in disease control. What is particularly interesting about the present study is that Chouvenc and colleagues could put this inference directly to the test under semi-natural conditions. They built mini termite nests and monitored the survival of colonies through time. Cleverly, by using nest material composed initially of sterile soil, the researchers could directly manipulate termite exposure to either friendly or harmful microbes. As anticipated, colonies exposed to pathogens died most rapidly. But when these colonies were also exposed to streptomycetes, the termites survived as well as they did in sterile soil. This result thus provided clear evidence that streptomycetes help protect Formosan termites against lethal infection, thereby providing them with a form of external immunity.

Less clear from this work is how this relationship evolved. Do termites specifically attract streptomycetes using faecal bait, perhaps farming them to exploit their antifungal secretions? Or do termites incidentally benefit from the fact that streptomycetes prolifically secrete antimicrobials to protect their own food, pre-digested wood pulp (termite faeces) in this case, from fungal competitors? Studies to distinguish these intriguing possibilities are in progress.

10.1242/jeb.094656

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The path of most resilience

Human activities are changing ecosystems around the world. Some species take these environmental changes in stride and are capable of surviving, or even thriving, in an altered landscape. However, other species are more sensitive, and decline or disappear. This variation in resilience to environmental change is a puzzle for scientists. Why there is such variation among species?

There are two possible paths to resilience in the face of environmental change. The first is for individuals to acclimatize, and alter their physiology so that they are better able to handle the new environment. The other path to resilience is through adaptation of the population, where only individuals that are suited to the altered environment survive and reproduce. So how do hardy species manage? Do they acclimatize or adapt?

One of the biggest current threats to marine ecosystem is ocean acidification. With increasing human consumption of fossil fuels, atmospheric CO_2 is rising. Atmospheric CO_2 then dissolves into ocean waters and increases the acidity.

An international team of researchers led by Piero Calosi from Plymouth University in the UK collaborated to investigate how species develop resilience to high CO_2. To conduct this research, the scientists took advantage of natural shallow CO_2 vents. While most species cannot survive if the CO_2 levels are too high, these natural ocean vents create localized areas of high CO_2, and are surrounded by a collection of species that thrive in the acidic conditions.

The researchers identified species of polychaete marine worms that live near natural CO_2 vents and are tolerant of elevated CO_2. The scientists also identified species of polychaetes that are sensitive to CO_2, and are never found in high CO_2 areas. The team then conducted two experiments. First, to determine how the tolerant and sensitive species differ in their responses to high CO_2, Calosi and colleagues collected both tolerant and sensitive polychaete species in low CO_2 areas. They transplanted these individuals near natural CO_2 vents, where CO_2 is high. Second, to determine whether tolerant species are acclimatizing or adapting to high CO_2, the researchers took tolerant species from natural vents and transplanted them to low CO_2 areas. In both experiments, the researchers measured metabolic rates of the polychaetes in their natural environment and in the transplanted environment. Metabolic rate is related to many crucial physiological processes, and gives insight into the scope of an organism for growth and reproduction.

The researchers found that tolerant species easily handled transplantation from low CO_2 to high CO_2 areas. However, the sensitive species responded dramatically. When transplanted near CO_2 vents, two of the sensitive species drastically lowered their metabolic rates, while individuals from the third sensitive species drastically increased their metabolic rates. The results were even more interesting when tolerant species were transplanted from natural CO_2 vents to more favourable low CO_2 areas. In one species, individuals adjusted their metabolic rates only slightly. In the second tolerant species, individuals increased their metabolic rates considerably when transplanted to low CO_2 areas, suggesting that there has been adaptation to high CO_2 in this species. Genetic analysis confirmed that this species could be divided into distinct groups originating from different high and low CO_2 regions.

These results have implications for both understanding extinctions and predicting species resilience in the face of future environmental change. Short-term acclimatization is a viable strategy, until long-term adaptation of the population can occur. There are indeed two paths to resilience, and on an evolutionary time scale, organisms need to exploit both of these paths if they are to survive and thrive in changing environments.

10.1242/jeb.094672

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