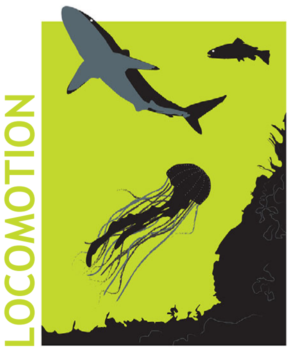
OUTSIDE JEB

Middle fins hold the key to fish movement



Next time you find yourself in an aquarium, pay attention to the fish's fins. The middle fins in particular show a mesmerising variety in number, shape and position on the fish's body. But what is the purpose of such a variation? David Matthews and George Lauder of Harvard University aimed to address this question by investigating the interactions between the middle and tail fins and their effect on a fish's movement. Biologists and engineers have previously attempted to navigate these tough waters, so what new angle did the pair introduce?

Matthews and Lauder used a simplified fish-like robotic model: a thin plastic foil mimicking the proportions and form of a fish (a fish body, a tail fin and two middle fins symmetrically arranged on either side of the body) connected to a robotic flapping device introducing a sideways movement with the help of motors. This model was a step closer to real fish than previous mechanical models, in which just the forces produced by the fins were investigated. On top of that, they decided not to control every aspect of the fish's movement, which would overcomplicate the robot-fish, but measure them instead. They attached a force-sensing rod to the front of the foil, where the fish's head would be, and changed the number of flapping cycles the body experienced per second to propel itself forward. Using this setup, they could quantify the foil's energy and movement such as its speed and the maximum amount each model fin flaps respectively, all together determining the swimming performance of this model fish.

With the robot-fish at hand, the authors first asked how the position of the fish's middle fins and the timing of their flapping, i.e. whether they flap in unison with the tail fin or not, affect its movement. They performed experiments with four types of robot-fish: flexible or stiff, and with middle fins near or far from the tail. They then showed that the number of flapping cycles per second has the largest effect on the fish's swimming performance, which is consistent with live fish that flap their fins more often when they want to accelerate. The modelling also revealed that the stiffness of the foil didn't significantly change its movement while the location of the middle fins did. The far-fin foil was always the fastest, and when the middle fins were moving out of sync with the tail fin, it was also the most efficient. The team also observed that the out of sync flapping of the fins was beneficial for force production, which varied less over time, costing less energy for the fish.

To understand these results further, Matthews and Lauder used a visualisation technique to look at the water flow around the fins. They showed that having middle fins is helpful as their flapping results in a strong side-to-side flow at the front of the tail fin – irrespective of the fin position in flexible foils. In contrast, they found that for the stiffer foils, the one with the far middle fins resulted in a direct interaction of its flow with the front of the tail fin, amplifying the production of the propelling force. Thus, they were able to conclude that the patterns of flow amplification are consistent with their statistical model and can help explain why fin position and flapping timing affect force production. As a result, while we previously knew that flow from one fish's body can impact swimming performance in following individuals, we now also know that following fish can independently improve their performance using their secret weapon – middle fins.

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Matthews, D. G. and Lauder, G. V. (2021). Fin–fin interactions during locomotion in a simplified biomimetic fish model. *Bioinspir. Biomim.* **16**, 046023. doi:10.1088/1748-3190/ac03a8

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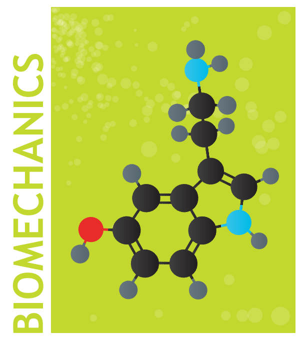
Adolescent prairie voles practice parenting



For many organisms, it takes a village to raise the young – individuals other than the youngsters' parents will provide care and help them to survive. In prairie voles, both adults and adolescents will care for babies, or pups, that are not their own. Recent work published by Caitlyn Finton and colleagues at Cornell University and Emory University, USA, suggests that adolescent prairie voles take care of pups to practice their parenting skills. But the hormones that drive adolescent caregiving behaviors are not the same as those that drive normal, adult parenting behaviors.

Finton and colleagues first tested why adolescent prairie voles would care for pups. The team thought that adolescents would either care for their siblings to pass on some of their related genes, or care for any pups that were around to learn how to become more competent parents in the future. The researchers raised families of prairie voles in the lab and chose adolescent males for their fostering experiments, as females tend to be more aggressive towards pups.

To test the adolescents' caregiving motivations, the researchers put the

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prairie voles in cages with a sibling of the same age, a sibling pup or an unrelated pup. They then recorded how the animals behaved toward each other using a video camera and counted the amount of time that the adolescents spent grooming, sniffing or huddling near the other voles.

As expected, the adolescent prairie voles spent a lot of time around the younger voles. The adolescents also spent more time grooming and cuddling the pups than they spent caring for siblings of the same age, which aligns with the idea that prairie vole teens help care for young.

However, the team found no difference in the amount of time adolescents spent grooming, cuddling or smelling related and unrelated pups. This suggests that adolescent male prairie voles are practicing their parenting skills on unrelated pups rather than caring only for siblings to pass on some of their genes.

Next, Finton and colleagues tested whether the brain activity that drives teenage caregiving is similar to the activity that drives adult parenting. They looked at the expression of genes in brain cells of adolescents to understand how changes in brain activity relate to differences in behavior, predicting that cells that produce the parenting hormones oxytocin and vasopressin would change their activity after caring for pups, but not after interacting with siblings or an inanimate object.

Surprisingly, the researchers found that cells that produce oxytocin and vasopressin had the same activity regardless of whether the adolescents interacted with the pups or their same-age siblings. This might be because the area of the brain they looked at, the hypothalamus, is not involved in adolescent caregiving, or it could be that other hormones, such as estrogen, drive the adolescents' behaviors towards pups.

Taken together, these results suggest that adolescent prairie voles raise pups to become better parents in the future, even if their teenage brains are not working like a parent's brain.

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Finton, C. J., Kelly, A. M. and Ophir, A. G. (2022). Support for the parental practice hypothesis: subadult prairie voles exhibit similar behavioral and neural profiles when alloparenting kin and non-kin. *Behav. Brain Res.* **417**, 113571. doi:10.1016/j.bbr.2021.113571.

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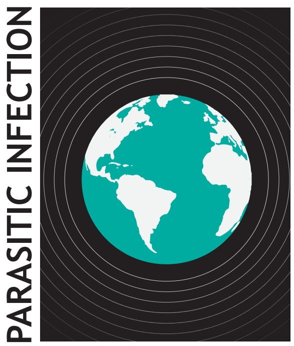
Got the travel bug?



Like many of us in 2021, I miss the glee of traveling to new and exciting locations on vacation (and can't wait to get back these adventures post-pandemic). Yet, what I don't miss are the inevitable bugs I pick up along the way. Whether it be a cold or a stomach flu, many of us come down with some sort of infection when we are away from home. Many things could contribute to these illnesses, including travel-induced sleep deprivation, novel foods or the concentration of viruses on mass transit. But, could it be that our bodies are just not primed to defend us against the diseases in foreign locales? Agnes Piecyk from the Max Planck Institute for Evolutionary Biology, Germany, and colleagues from the USA and Germany wanted to investigate this theory to figure out whether hosts and parasites develop specialized relationships depending on their geographic origin.

So, they took advantage of a host–parasite system that is found throughout the northern hemisphere: the three-spined stickleback *Gasterosteus aculeatus* and its tapeworm *Schistocephalus solidus.* The stickleback picks up this nasty worm in a way commonly found on our own human travels – in its food. One of its favourite foods, the copepod, is commonly infected by this parasite. Once consumed, the parasite burrows through the fish's gut, invading its body and quickly growing to fill every nook and cranny of the fish's insides. The parasite steals much of its host's food, forcing the stickleback to feed constantly to keep up with its own energy needs and the demand of its unwanted guest. This voracious feeding makes it less likely to take shelter to avoid predators because of an overwhelming need for food, attracting the attention of its primary predators – and the next host in the parasite's life cycle – fish-eating birds. The parasite then gladly makes its way to the bird's gut, where it sexually reproduces, starting the process again when the bird deposits the parasite's eggs back into waterways containing the copepod (its first host) through its feces. This incredible chain of events has evolved through an evolutionary arms race among the parasite and its three host species.

Using sticklebacks and tapeworms from Europe and Alaska, the researchers set about testing the feasibility of inter-continental infections, exposing Alaskan sticklebacks to European tapeworms and vice versa. Surprisingly, while the Alaskan parasite readily infected the European fish host, the Alaskan stickleback put up a stronger fight against the European tapeworm, with hosts from certain Alaskan regions effectively preventing infection altogether. For those unlucky fish that succumbed to infection, their worms varied greatly in size depending on the host's origin. In addition, even when the Alaskan sticklebacks did pick up an infection, their immune systems succeeded in keeping the worm in check, with much smaller worms relative to their body size than European sticklebacks. While we would typically cheer the hosts that entirely prevented a parasite invasion, those uninfected sticklebacks were skinnier than otherwise healthy sticklebacks, indicating the hidden energetic cost of their unseen battle.

While the researchers' work sheds light on the complex interactions between hosts and parasites on a local scale, we still have much to learn about how these geographic differences develop and whether there are epidemiological implications due to geographic differences in disease susceptibility. And hopefully this knowledge might one day help us to avoid the dreaded vacation bug (once we are finally back out there, galivanting in exciting new places).

doi:10.1242/jeb.237479

Piecyk, A., Hahn, M. A., Roth, O., Dheilly, N. M., Heins, D. C., Bell, M. A. and Kalbe, M. (2021). Cross-continental experimental infections reveal distinct defence mechanisms in populations of the three-spined stickleback *Gasterosteus aculeatus*. *Proc. R. Soc. B.* **288**, 20211758. doi:10.1098/rspb.2021.1758

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Tardigrades coordinate microscopic eight-legged gallop

Tardigrades are squidgy, microscopic animals with eight legs and a penchant for watery habitats. It's tempting to consider them cuddly, especially given their nickname 'water bears'; however, it's hard to hug an animal measuring less than 1 mm. Despite their soft exterior, they are famed for their hardened resistance against the harshest possible conditions. Freeze them, heat them, dry them out, irradiate them – tardigrades take it all in their stride. For this reason, they can be found in every corner of Earth and even in space, with the latest batch of tiny tardigrade astronauts sent to the International Space Station earlier this year.

But being small has its challenges. For a tardigrade, taking a walk through a droplet of water is like you or me trudging our way through a bucket of mud. Despite this, tardigrades appear to quite happily walk and swim, using their tiny clawed feet to propel themselves forward. Given that their habitats are complicated three-dimensional environments and they have limited brain space, how are tardigrades able to negotiate their microscopic worlds? Jasmin Nirody from the University of Oxford, UK, together with Daniel Cohen and Lisset Duran from Princeton University, USA, and Deborah Johnston from the University of Rochester, USA, were curious and so began investigating how tardigrades would fare when given a variety of different surfaces to walk over.

Using a light microscope and video camera, Nirody and colleagues designed a performance arena for the terrestrial species *Hypsibius exemplaris* and first observed the tardigrades walking freely over a stiff gel-like substance, taking note of the animals' speed and pattern of their footfalls. They found that the tardigrades' feet on the left and right sides moved independently from each other, but their feet on a given side were tightly coordinated according to two basic rules: first, that if one leg was swinging forward, the adjacent leg in front or behind had to be on the ground; and second, that any given leg would only lift off the ground once its rear neighbouring foot touched down. Nirody and colleagues had seen this pattern before in much larger animals, such as fruit flies, and they suspect that these walking rules are governed by simple neuronal circuits composed of a series of on–off switches.

Having watched the tardigrades fare well on the stiff gel surface, Nirody and colleagues then decided to give the mini beasts a bit of a challenge; could a tardigrade with a soft body walk on soft ground? This time, Nirody provided the animals with a softer, more jelly-like surface to walk on and the tardigrades adapted their walking style by adjusting the synchronisation between their left and right sides. More incredibly, their new stepping pattern resembled the gallop seen in dung beetles moving over shifting sands. Nirody and colleagues suggest that perhaps this is a strategy used by both arthropods and tardigrades when navigating tricky terrain.

The tardigrades' performance and similarities with insects have two possible explanations, which are equally absorbing. Either insects and tardigrades share a common ancestor which has 'gifted' them with similar patterns of coordination or, despite their huge difference in size and anatomy, tardigrades and insects have independently arrived at similar strategies to propel their bodies in challenging environments. With tardigrades now living in orbit, 'one small step' carries new meaning.

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Nirody, J. A., Duran, L. A., Johnston, D. and Cohen, D. J. (2021). Tardigrades exhibit robust interlimb coordination across walking speeds and terrains. *Proc. Natl. Acad. Sci. USA* **118**. doi:10.1073/pnas.2107289118

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Environmental cocaine places mussels at risk by increasing neurotransmitters

When going to the beach for a swim, probably the last thing on your mind is whether you are swimming in a thin soup of drug traces. Whether prescribed over the counter or illegal, many drugs taken by people wind up in our waterways. These drugs cannot be removed by wastewater treatment plants and thus get released back into the environment. A famous coastal region in Brazil, the Bay of All Saints (Baía de Todos os Santos in Portuguese), has been the subject of multiple environmental contaminant studies and researchers have found measurable quantities of cocaine in the seawater, sediment and mussels (*Perna perna*) of the bay. Although the environmental concentrations are too low to affect humans, whether cocaine at these levels has an effect on the nervous system of aquatic species that reside in the bay was unknown. So, Mayana Fontes and a team of researchers from Universidade Estadual Paulista Júlio de Mesquita Filho, Brazil, and other universities in Brazil investigated how levels of cocaine in the seawater affect the nervous system of *P. perna* mussels.

Fontes and colleagues placed adult mussels in tanks containing seawater with two different concentrations of cocaine that were realistic for the Bay of All Saints (0.2 and 2 μg l^{-1}) for 2, 4 or 7 days. Then, they collected the adductor muscles, which open and close the shell, and gonads of these mussels. In the adductor muscle, they measured the activity of acetylcholine esterase, an enzyme essential for a functioning nervous system. In the gonads, they measured the levels of two major neurotransmitters, serotonin and dopamine, the activity of the enzyme that breaks down these neurotransmitters, monoamine oxidase, and the activity of cyclooxygenase, an enzyme that is a sign of inflammation and is important for egg release in mussels. In addition, the authors also measured how much energy the mussels spent during the exposure to cocaine by measuring mitochondrial electron transport activity, and how much energy they set aside by measuring the level of total lipids in the gonads.

The team found that mussels exposed to cocaine had a decreased acetylcholine esterase activity in the adductor muscle, which shows that cocaine disrupted the normal activity of the nervous system. They also found that mussels exposed to cocaine had raised levels of dopamine and serotonin. These neurotransmitters are essential for reproduction, and changes could lead to an unsustainable population in the wild. The mussels also increased cyclooxygenase activity in the gonads, which shows an inflammatory response to low doses of cocaine. In addition, the scientists found changes in the mitochondrial electron transport chain – which converts the energy from oxygen into ATP in the mitochondria – directly increasing the amount of energy the mussels spent after exposure to the drug, which decreases the amount of energy they can access for reproduction as energy is limited. Finally, they also found that there was an increase in levels of total lipid, which act as a convenient and easy to access energy source for the animals.

Fontes and colleagues have shown that the current concentration of cocaine in the seawater around the Bay of All Saints can negatively impact the area's mussels in complex ways and this may put them at a greater risk from other chemicals that we dump into the environment.

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Fontes, M., Dourado, P., de Campos, B., Maranho, L., de Almeida, E., Abessa, D. and Pereira, C. (2022). Environmentally realistic concentrations of cocaine in seawater disturbed neuroendrocrine parameters and energy status in the marine mussel *Perna perna*. *Comp. Biochem. Physiol. C* **251**, 109198. doi:10.1016/j.cbpc.2021.109198

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