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how the insects responded in practice. Constructing a Lego brick wall, a three-sided cul-de-sac and a completely enclosed corral coated in slippery Fluon® – to prevent the ants from escaping over the top – McCreery and Zachary Dix placed each one in the path of a crew of longhorn crazy ants (*Paratrechina longicornis*) as they attempted to heft chunks of tuna home, and then filmed the ants' tactics.

Analysing the ants' manoeuvres when they encountered the wall, the team saw that the obstructed ants simply moved to and fro along the wall until they reached the end and resumed their homeward course. 'Ants are really good at knowing the direction of the nest', says McCreery, explaining that the ants needed little information other than the direction of home to implement this strategy. However, using the same tactic when faced with a cul-de-sac would be doomed to failure. Realising that the strategy for escaping a blind alley must be more sophisticated, the team watched as the ants zig-zagged to and fro across the front wall of the obstruction – as they had when trying to navigate around the wall. However, as time passed, they began randomly moving backwards, away from the nest, until eventually they encountered the exit and were able to go on their way again. The ants' strategy of using random movements allowed them to maintain a consensus while being flexible and robust enough to get them out of most tight corners, although the route that they took was not always the most efficient.

However, McCreery admits that she was surprised at how quickly the ants gave up and abandoned their precious piece of tuna when they found themselves trapped in the corral. 'We really expected their behaviour in the trap to look a lot like the cul-de-sac, at least at the beginning. But as soon as we closed the door, the speed and group size started to drop', she recalls, suggesting that the ants might have given up sooner than expected because they were cut off from incoming ants. And, having discovered how ants deal with being stuck in a blind alley, Nagpal is keen to apply these strategies to teach teams of robots how to cooperate to solve problems in environments that they are unfamiliar with.

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Kathryn Knight

Drag has not shaped mantis shrimp weapons

A male *Odontodactylus scyllarus* mantis shrimp smashing a common periwinkle. Photo credit. Roy Caldwell.

Whether pulverising their victims with a powerful single blow or impaling them with a lethal harpoon, feisty mantis shrimps more than live up to their Australian nickname of 'thumb splitter'. Their blows can be so forceful that a thump from one of their appendages can even tear water apart, producing a distinctive flash of light as the resulting bubble implodes. How the weapons of different mantis shrimp species have been moulded by their watery environment is a puzzle that fascinates Sheila Patek from Duke University, USA. With a long history of investigating the predatory crustaceans, Patek has now turned her attention to try to understand how the drag forces experienced by the stomatopods' limbs have shaped the design of their weapons.

Having already analysed the motions of several hammer-wielding mantis shrimps (*Neogonodactylus bredini*, *Odontodactylus scyllarus*, *Gonodactylus smithii*) and harpooners (*Lysiosquillina maculata* and *Alachosquilla vicina*), Patek teamed up with undergraduate David Matthews at the University of Massachusetts, USA, to add another spearer to the list: *Coronis scolopendra*. Filming the action of the medium-sized new recruit at 15,000 frames s^{-1} and comparing its performance with that of the other species, Patek could see that the smallest animals hurled their weapons faster than the larger animals. However, the high-speed movies could not tell her about the drag acting on the differently shaped and sized appendages, so Patek collaborated with Adam Summers from the University of Washington, USA, to produce scaled up models of the appendages of all six species, which Philip Anderson then tested in a horizontally flowing flume to measure the drag that they experienced. As the final segment of the limb, the dactyl, swings out during the early stage of the flicking motion, Anderson measured the drag on the limbs and found little difference between the different designs. However, the drag on the smashers' limbs increased when the limb was fully extended, while the harpooners were no more impaired by drag when the limb was fully extended.

However, Patek explains that when the armoured limbs are launched during an attack, they do not move in a straight trajectory. Instead, the mantis shrimps swing their hammers and harpoons in an arc, and this can dramatically alter the drag forces that they experience. So Patek collaborated with two colleagues, Sam Van Wassenbergh from the University of Antwerp, Belgium, and Matt McHenry from the University of California, Irvine, USA, to test two different types of drag simulation to find out how well they agreed on the impact of drag on the differently sized and shaped limbs. Explaining that one of the simulation techniques (computational fluid dynamics) is known to be extremely precise but extraordinarily time consuming, while the second (blade element analysis) takes a more simplified approach but is speedier, the team compared the results of the calculations and found that McHenry's blade element analysis was remarkably accurate, despite its simplicity; 'This study demonstrates the utility of simple mathematical modelling for comparative analyses', says Patek.

Considering the implications of the calculations, which showed that drag has a minor impact on the weapon shape, Patek says, 'This suggests that drag forces have not stymied the spectacular diversification of mantis shrimp appendage shapes, including hatchets, spears and hammers, that are used for impaling and crushing prey'. So, while drag can have a significant effect on body shape for motion, other factors – such as robustness and making an easy catch – probably have more of an impact on weapon design when the next meal is at stake.

10.1242/jeb.151415

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