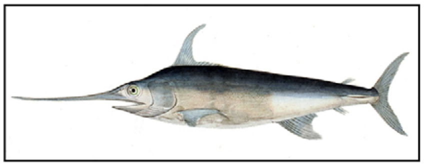
INSIDE JEB

Swordfish lubricate heads for speedy swim



Xiphias gladius. By Werner (Histoire Naturelle des Poissons); Public domain, via Wikimedia Commons.

Reminding us of a bygone era of duelling and chivalry, swordfish are some of the most charismatic creatures in the open ocean. Embellished with a rapier-like bill – which has been known to impale boats – and alleged to reach speeds of 100 km h^{-1}, these animals have fascinated humans since the earliest civilisations. However, swordfish may be less fearsome than their anecdotal reputation would have us believe. 'They have no teeth', says John Videler from Groningen University, The Netherlands, who explains that they probably dine on squid. And their formidable proboscis may be less robust than you would first assume: 'Last summer, an article by Maria Habegger [and colleagues] appeared in JEB… and they were surprised to find that there is a very weak spot just at the end of the sword where it enters the head', says Videler. Intrigued by the fish's apparent vulnerability, Videler decided to revisit some MRI scans that he had collected 20 years earlier to identify the source of the fish's weakness.

Recalling that he first encountered the exotic animals in 1995 when he acquired a swordfish bill while teaching a diving course for biologists in Corsica, Videler eventually discovered that the sword reduces the amount of drag pulling on the fish as it sweeps through the ocean. Roughness at the tip of the bill generates microturbulence in the water, to make it 'thinner' and reduce the drag, which improves performance. So, when some of Videler's fishermen friends offered him a pair of swordfish, Videler couldn't resist the urge to MRI scan the entire animals using Ben Szabo's medical MRI scanner in Groningen. 'We started at 2 a.m. and went on to 4:30 a.m.', chuckles Videler, who recalls that transporting the fish intact from Corsica to The Netherlands was challenging.

Having returned to scrutinise the images 20 years later, Videler was astonished when the cause of the weakness was instantly apparent. 'I saw this gland', says Videler, adding, 'It was so big there was hardly any room for bony structure and the bone around it was very thin'. However, the purpose of the gland wasn't initially clear.

Suspecting that the gland may be linked in some way to the nasal opening in the head, Videler and Roelant Snoek searched for evidence of a link with the fish's olfactory system, but found none. It was only when Snoek inadvertently dropped a lightbulb onto the fish's skin that the function of the gland was revealed. 'All of a sudden he saw this network of vessels that were connected to the oil gland', says Videler. Next, Deniz Haydar and Henk-Jan Hoving examined the surface of the skin with scanning electron microscopy and discovered that the head was covered in tiny holes that were connected to the gland by the capillaries: 'And then we found that by heating up the gland you could see oil come out of these tiny little holes', says Videler.

The gland that was responsible for the weakness at the base of the swordfish's appendage is probably lubricating the fish's head as it scythes through the water, and Videler suspects that the oil, in combination with microscopic rough projections on the skin, might produce a surface that is super water-repellent and could reduce the drag on the animal by over 20%. However, he admits that testing this theory would be difficult as swordfish cannot be kept in captivity, so he is hoping instead to challenge physicists to test simulated swordfish skin to find out just how slick swordfish heads could be.

10.1242/jeb.144691

Videler, J. J., Haydar, D., Snoek, R. Hoving, H.-J. T. and Szabo, B. G. (2016). Lubricating the swordfish head. *J. Exp. Biol.* **219**, 1953-1956.

Kathryn Knight

High-altitude bar-headed geese outperform Vancouver cousins

Bar-headed geese, China. Photo credit: Moffat Photography.

When it comes to feats of extreme endurance, bar-headed geese leave most animals in their wake – even other birds. Migrating back and forth across the Himalayan Mountains from their northern nesting grounds to overwinter in South Asia, the large birds have to sustain flight – one of the most metabolically demanding activities – at altitudes where oxygen is scarce. Sabine Lague and colleagues from the University of British Columbia and Queen's University, Canada, explain that most birds are well equipped to deal with the metabolic demands of flight, and bar-headed geese have souped-up systems to ensure that they deliver sufficient oxygen to their toiling flight muscles in the thinnest of air. However, the team explains that most of our understanding of the physiology of these extreme aviators is based on observations of animals raised at sea level; yet, the true athletes are born and raised at altitudes of over 3000 m on the Tibetan and Mongolian plains.

Curious to find out how acclimatisation and growing up in a rarefied atmosphere affects the birds' respiratory and cardiovascular systems, Lague, Beverly Chua, Tony Farrell, Yuxiang Wang and

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Bill Milsom set up a lab on the shores of the high-altitude Lake Qinghai, China, to find out how the birds' ventilatory and cardiovascular systems compared with those of bar-headed geese raised back in Vancouver at sea level.

The team gently cradled the birds in a sling and placed their heads in a large Plexiglas chamber to measure oxygen consumption. They also recorded the pH, the concentrations of certain ions, and the oxygen content of the blood, in addition to measuring blood pressure and other cardiac variables to monitor how the hearts coped as the oxygen supply was gradually reduced to levels in excess of those experienced during the epic migration. Impressively, Lague and colleagues found that the high-altitude animals had lower metabolic rates than the sea-level birds and the Tibetan geese were able to breathe harder than the Vancouver birds as the oxygen levels plummeted. However, when they scrutinised the oxygen carrying capacity of both groups of birds, the high-altitude birds carried no more oxygen than the birds reared at low altitude. And when the team analysed the function of the birds' cardiovascular system, they found that their hearts were able to pump blood just as effectively when the oxygen supply was high, but as the oxygen supply was reduced, the hearts of the birds from Lake Qinghai were able to pump blood at twice the rate of those from the geese raised in Canada.

'High-altitude-reared bar-headed geese exhibit a reduced oxygen demand at rest and a modest but significant increase in oxygen uptake and delivery during progressive hypoxia compared to low-altitude-reared bar-headed geese', say Lague and her colleagues, who are now keen to know more about the mechanisms that allow the Tibetan bar-headed geese to outperform their cousins in British Columbia.

10.1242/jeb.144709

Lague, S. L., Chua, B., Farrell, A. P., Wang, Y. and Milsom, W. K. (2016). Altitude matters: differences in cardiovascular and respiratory responses to hypoxia in bar-headed geese reared at high and low altitudes. *J. Exp. Biol.* **219**, 1974-1984.

Kathryn Knight

Respiration timing is key for estimating cetacean energetics

A killer whale surfacing. Photo credit: Marjoleine M. H. Roos.

The amount of oxygen that an animal consumes as it goes about its daily activities can teach us how that creature integrates into its environment, how much food it must consume and whether its lifestyle is sustainable in increasingly disturbed ecosystems. However, our understanding of the energetics of some of the most enigmatic inhabitants of the oceans remains sparse. 'Measuring metabolic rates of the free-ranging cetaceans directly is unfeasible', says Marjoleine Roos from the University of St Andrews, who explains that scientists had previously used the respiration rate of surfacing whales and dolphins as a proxy for elusive metabolic rate measurements. 'However, doing so assumes that every respiration reflects a fixed amount of oxygen take up, whereas oxygen uptake has been shown to fluctuate per respiration', says Roos. In addition, metabolic estimates based on this assumption have failed to identify the optimal swimming speeds for ocean-going mammals. Inspired by these potential failings, Roos and Patrick Miller decided to test the accuracy of a new oxygen consumption model in a bid to better understand the energetics of free-ranging killer whales.

Attaching digital acoustic recording tags (DTAGs) to 10 killer whales over a 4 year period, Miller recorded the animals' movements and the sound of water rushing past as they swam and dived, which the team then analysed to learn more about the animals' activities. According to Roos, killer whales are single-breath divers, continually diving between visits to the surface, rather than resting at the surface for extending periods to recover like other species. Roos and Miller had assumed that the animals would increase their respiration rate as they speeded up and used more energy, if they were inhaling the same amount of oxygen each time they surfaced. However, when the duo and Gi-Mick Wu examined over 50 h of recordings and calculated the animals' respiration rates, they were puzzled to see that they did not increase. 'We considered that there must be some breath-to-breath variation in oxygen uptake that wasn't accounted for by respiration rate alone', says Roos.

The team recalculated the inhalation values based on respiration measurements taken from captive killer whales and adjusted the amount of oxygen that they took on board in response to the amount of oxygen that they retained after the previous dive, and the rate at which it was replenished. This time, they were impressed to see that their simulations produced realistic predictions for the amount of oxygen carried by the diving animals, and when they calculated the amount of oxygen consumed as the animals swam at different speeds, they found that the cost of transport was lowest at speeds ranging from 1.7 to 2.4 m s^{-1}. 'The predicted cost of transport was substantially lower than previous studies have predicted for killer whales. This could be vitally important as it might indicate that killer whale feeding requirements are much lower than previously thought', says Roos. These new estimations could have significant implications for our understanding of their ecology.

Having found the killer whales' optimal swimming speed, Roos warns that estimates of the amount of energy used by cetaceans based on their respiration rate alone could be unreliable and she recommends that scientists begin considering when cetaceans inhale air relative to the amount of oxygen that they are carrying to build a better understanding of the ecology of some of the ocean's top predators.

10.1242/jeb.144725

Roos, M. M. H., Wu, G.-M. and Miller, P. J. O. (2016). The significance of respiration timing in the energetics estimates of free-ranging killer whales (*Orcinus orca*). *J. Exp. Biol.* **219**, 2066-2077.

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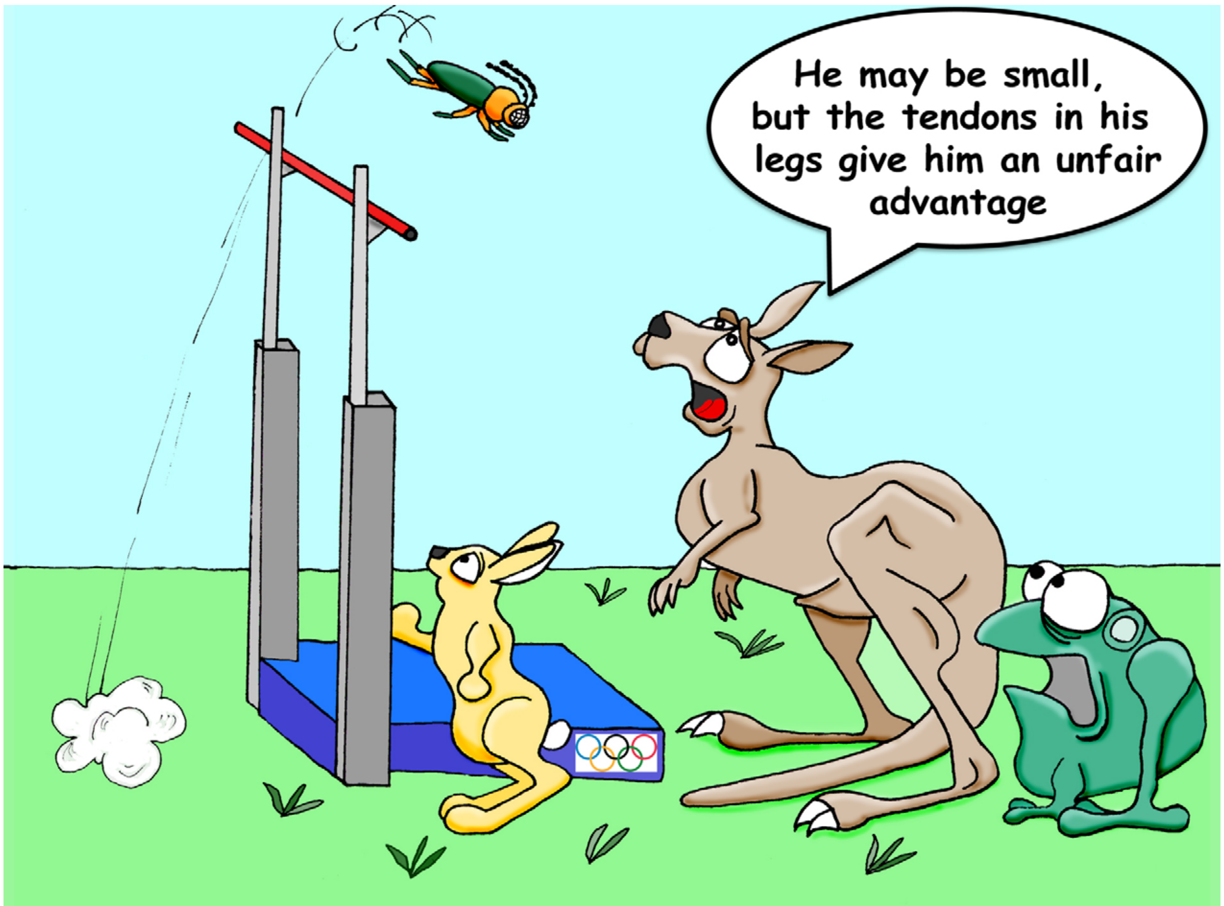
Spring-loaded flea beetles go ping



Horticulturalists have a love–hate relationship with flea beetles. While some species keep weeds in check, others are pests with a voracious appetite for the crops we cultivate. And these diminutive pests have another claim to fame: they perform spectacular leaps to evade predators when startled. Konstantin Nadein and Oliver Betz from the University of Tübingen, Germany, explain that the insects have fascinated scientists since the 1920s: 'Nevertheless … the exact mechanism of energy storage and release in [jumping] flea beetles is still not fully understood', they say. Intrigued by the tiny beetles' agility, Nadein and Betz filmed the antics of seven members of the flea beetle family and scrutinised their anatomy to pin down the fine details of the feat.

Filming the explosive leaps at 2000 and 3000 frames s^{-1}, the duo could see the beetles taking off in less than 2.25 ms, reaching ***g***-forces of up to 340 and hitting top speeds of 3.6 m s^{-1} (the equivalent of a human jumping at almost 2.5 km s^{-1}) as they pinged themselves into the air. Also, when the pair used high-powered scanning electron microscopy, X-rays and fluorescence microscopy to look at the structures inside the beetles' legs, they saw a specialised stretchy tendon linking the femur and tibia that can store an enormous amount of energy, which is released instantaneously when the flexor muscles – holding the tibia in place during the preparation phase of the jump – suddenly relax. Nadein and Betz say, 'The calculated specific joint power (max. 0.714 W g^{-1}) of the femoro-tibial joint during the jumping movement and the fast full extension of the hind tibia (1–3 ms) suggest that jumping is performed via a catapult mechanism'.

10.1242/jeb.144717

Nadein, K. and Betz, O. (2016). Jumping mechanisms and performance in beetles. I. Flea beetles (Coleoptera: Chrysomelidae: Alticini). *J. Exp. Biol.* **219**, 2015-2027.

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