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Inside JEB

HARBOUR SEAL WHISKERS DETECT FISH TRAILS 35 s LATER

When a hungry harbour seal sets off in pursuit of a fish diner, the animal has a secret weapon in its tracking arsenal: its whiskers. Detecting the trails left by fish in the water with their sensitive whiskers, seals easily track passing fish even in the most turbid conditions. Wolf Hanke from the University of Rostock, Germany, explains that blindfolded seals can track passing mini-submarines for a distance of 40 m before the wake peters out. However, the hydrodynamic trails left by subs are different from those produced by fish fins, so how long could a seal track a trail generated by a moving fin before the turbulence became too faint to follow (p. 2194)?

PhD student Sven Wieskotten, together with Hanke, Guido Dehnhardt, Björn Mauck and Lars Miersch, decided to find out how 6-year-old Henry, a harbour seal living at the Marine Science Centre, Germany, would respond to ageing hydrodynamic trails. Isolating a section of calm water in a subsurface enclosure, Wieskotten and Hanke covered Henry's eyes with a blindfold and trained him to poke his head into the Perspex box a few seconds after they had swept a small rubber fin through the still water. Then they trained Henry to indicate which direction he thought the fin had moved by rewarding him with a tasty fish snack whenever he was correct.

After 2 months of training, Henry was ready to tell the team which direction he thought the fin was moving. Guided only by his whiskers, the team allowed Henry to swim into the enclosure 5 s after the fin swept through the water and was delighted when Henry successfully identified which direction the fin had moved with over 90% accuracy. Gradually increasing the length of the delay, Wieskotten and his colleagues were amazed that even after a 35 s delay Henry was able to tell them which direction the fin had passed with 70% accuracy. However, after a 40 s delay, Henry lost the trail.

Curious to find out more about the fin's decaying trail, the team added microscopic spheres to the water and filmed them as they swirled through a plane of laser light. Analysing the particles' movements, they found spinning vortices producing jets of water that were very similar to those found in genuine fish wakes. Also, the wake became more dispersed as it decayed, covering a width of 20 cm 5 s after the fin swept past and expanding to 50 cm 30 s later. And when the team filmed the wake's interaction with Henry's whiskers, they could see Henry twitch his head in the direction that the fin had moved within 0.5 s of the plume touching his whiskers. The wake only had to brush over the seal's whiskers for him to know which direction the fin had passed.

The team suspects that harbour seals sense the structure of the wake's vortices and jets to determine which direction a fin moved and is amazed that the animals can still detect a fin's motion over half a minute later. 'A fish can cover tens and hundreds of metres in that time, so vibrissae [whiskers] compare well with the performance of whales and dolphins by echolocation,' says Hanke.

10.1242/jeb.047258

Wieskotten, S., Dehnhardt, G., Mauck, B., Miersch, L. and Hanke, W. (2010). Hydrodynamic determination of the moving direction of an artificial fin by a harbour seal (*Phoca vitulina*). *J. Exp. Biol.* **213**, 2194-2200.

YELLOW AND BLACK PLUMAGE IS NOT A CONTRADICTION

Everyone likes to look good, and greenfinches are no exception. They tell the world how fit and well they are through the brightness of their plumage. Peeter Hõrak from Tartu University, Estonia, explains that the carotenoids – which produce vivid yellow, orange and red pigments – were believed to function as antioxidants protecting birds from the damaging effects of oxidation: the brightest birds were thought to be the strongest because of their resistance to oxidative damage. Dark black feathers are also a sign of fitness, but black melanin pigments can only be produced if the levels of a powerful antioxidant, glutathione, are low, leaving the bird vulnerable to oxidative damage. So being fit with bright yellow feathers and maintaining strong antioxidant defences would seem to be incompatible with simultaneously having healthy black feathers, where the bird's antioxidant defences are low. But greenfinches seem to handle this contradiction fine; they have yellow and black tail feathers. Intrigued by the contradiction, Hõrak and his colleagues decided to find out what messages birds' colours send (p. 2225).

Collecting wild greenfinches from around Tartu, Hõrak and his students Elin Sild and Tuul Sepp brought them back to the lab. Supplementing the diets of some of the birds with carotenoid spiked water and reducing the glutathione levels of others with injections of buthionine sulfoximine, the team plucked one yellow and black tail feather from each bird and then waited for the feather to grow back to see what effect the treatments had on their colours.

Monitoring the birds' health while waiting for the feathers to grow, the trio also teamed up with two medical biochemists, Kalle Kilk and Ursel Soomets, to measure the greenfinches' levels of malondialdehyde, which shows the amount of oxidative damage sustained by the animal. 'Kilk and Soomets have a good and reliable assay for measurement of malondialdehyde based on HPLC and mass spectrometry that we used to show whether there is a clear link between oxidative damage, glutathione and black coloration,' explains Hõrak.

Measuring the darkness of the tips of the newly grown tail feathers, the team saw that the birds that had received glutathione reduction injections had low glutathione levels, the darkest feathers and suffered the highest levels of oxidative damage. Hõrak explains that the greenfinches' black tail feather tips were showing that the birds were fit because they were tough enough to cope with disease: like drinkers that consume too much alcohol and brag about 'being able to take it'. But what effect did the carotenoid supplemented water have on the birds' health and plumage?

Sure enough, the yellow portion of the new tail feathers grown by the greenfinches on a carotenoid supplemented diet were brighter than the tail feathers of birds that did not have additional carotenoid. However, the carotenoids did not protect the birds from oxidative damage. Kilk and Soomets' measurements showed that the birds' malondialdehyde levels were as high as those of the birds who did not receive additional carotenoid. The carotenoid boost had not protected them from oxidative damage.

So bright yellow feathers do not signal the birds' resistance to oxidative damage, which answers Hõrak's initial question: there is no contradiction. Birds can have bright yellow and dark black feathers at the same time because the colours send different messages. While black pigments are attractive because they signal that a bird has good defences and is tough, it is less clear what bright yellow plumage signifies; but whatever it is, the lady birds love it.

10.1242/jeb.047266

Hõrak, P., Sild, E., Soomets, U., Sepp T. and Kilk, K. (2010). Oxidative stress and information content of black and yellow plumage coloration: an experiment with greenfinches. *J. Exp. Biol.* **213**, 2225-2233.

SURF PERCHES STAY AEROBIC IN HIGHER SPEED GAITS

All animals shift gear as they speed up. Horses switch from walking to trotting to galloping. They do this to conserve energy, changing to a higher gear when the cost of transport becomes too high. Fish also change gait as they speed up. Surf perches start out swimming with their pectoral fins at low speeds, before shifting to tail swimming and finally the burst and coast gait – where they intersperse swimming, using the tail, with coasting, using the pectoral fins – but no one knew the cost of transport of these gaits. According to Jon Svendsen, Eliot Drucker and Jeff Jensen put striped surf perches through their paces in the 1990s and suggested that the fish switch from aerobic respiration (fuelled by oxygen) to anaerobic respiration (not fuelled by oxygen) as they switch from one gait to another, but no one had tested the idea. Discussing the problem at a Friday Harbor Laboratories (University of Washington) Fish Swimming Class in 2005 with fellow students and mentors, Cristian Tudorache, Anders Jordan, John Steffensen and Paolo Domenici, the team decided to find out find out how striped surf perches manage their metabolism as they speed up through higher gaits (p. 2177).

Collecting surf perches from Puget Sound, the team placed individual animals in a swimming respirometer and measured their oxygen consumption rates. Setting the swimming speed at a leisurely 34 $cm\,s^{-1}$, before ramping it up to 46 $cm\,s^{-1}$ and finally a top speed of 56 $cm\,s^{-1}$, the team filmed the fish and measured their oxygen consumption rates as they swam. After swimming the surf perches for half an hour at each speed, the team reduced the swimming speed to give the fish time to recover if they had switched to anaerobic metabolism. If the fish had been swimming anaerobically, their metabolic rate would be much higher during the recovery period than if they had been swimming aerobically, allowing the team to calculate how much energy the fish were supplying aerobically and anaerobically at each gait.

Back in Denmark, Svendsen's supervisor, Kim Aarestrup, joined the team to analyse the movies of the fish swimming and analysed their swimming gaits. At the slowest speeds, the fish generated lift and thrust by flapping their pectoral fins alone, but when they began moving at the second speed they recruited their tail fin in addition to the pectoral fins. Finally, at the top speed, the surf perches alternated bursting forward using the tail and coasting on the pectoral fins.

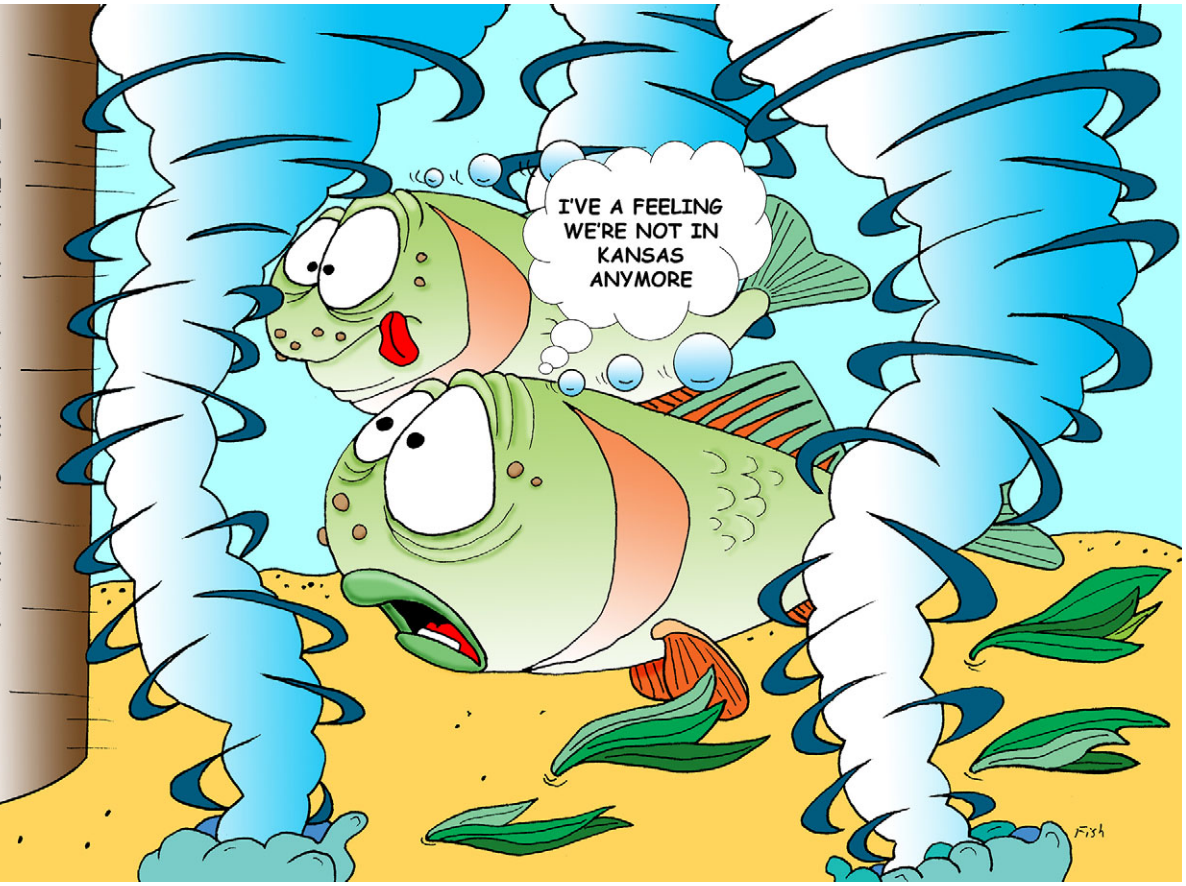
Correlating the respirometry readings with each gait, the team found that instead of supplementing their energy supply with anaerobic metabolism as they switched from the first to the second gait, the fish were able to keep going at the higher speed fuelled by aerobic metabolism alone. They only began supplementing aerobic metabolism with anaerobic metabolism at the highest speed.

The fact that the fish swim aerobically when using the tail in second gear is puzzling. Svendsen and his colleagues explain that only 0.3% of the muscle that powers the tail is aerobic red muscle so it seems unlikely that the red muscle alone can power the second gait tail beats. The team is curious to find out how the fish do this when 99.7% of the tail-beating axial muscles respire anaerobically and suspect that the fish switch gait to supply more power from the axial muscles for swimming at high speeds.

10.1242/jeb.047241

Svendsen, J. C., Tudorache, C., Jordan, A. D., Steffensen, J. F., Aarestrup, K. and Domenici, P. (2010). Partition of aerobic and anaerobic swimming costs related to gait transitions in a labriform swimmer. *J. Exp. Biol.* **213**, 2177-2183.

HOW FISH HANDLE EDDIES



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Most experiments that look at how fish swim observe the animal's movements in smooth flowing water; however, the real world isn't like that. Fish routinely encounter swirls and eddies that threaten to throw them off course; but by how much and how do they cope? Hans Tritico now at Youngstown State University, USA, and Aline Cotel at the University of Michigan, USA, decided to find out how eddies affect creek chub by putting the fish in a turbulent water tunnel and filming the water's motion and the fish's responses (p. 2284).

Disturbing the water's flow, with either vertical or horizontal cylinders, the duo generated small eddies (diameters up to 40% of the fish's body length) and large eddies (diameters of 92% of the fish's length) using 0.4 cm, 1.6 cm and 8.9 cm diameter cylinders. While the fish were unfazed by the smaller scale eddies, the larger eddies were more of a problem and horizontal eddies with diameters greater than 75% of the fish's length knocked the fish off course almost 2.5 times more often than the vertical eddies of the same size. In the most turbulent conditions the maximum swimming speed of fish was reduced by as much as 20%. The fish also followed a set recovery routine when they tumbled in the vertical eddies and added two additional body rolls as they righted themselves after spills in the horizontal eddies. Tritico and Cotel also noticed that the fish preferred swimming downstream of the gaps between the large cylinders when the water flowed slowly, but retreated behind the cylinders as the horizontally turbulent water speeded up, while settling behind the cylinder edge in high speed flows through the vertical cylinders.

So fast rotating horizontal eddies with a diameter similar to the fish's length pose the greatest challenge to fish swimming in the natural environment and Tritico and Cotel suggest that 'the importance of eddy diameter, vorticity, angular momentum and orientation have the potential to improve future fishway and stream restoration design'.

10.1242/jeb.047274

Tritico, H. M. and Cotel, A. J. (2010).The effects of turbulent eddies on the stability and critical swimming speed of creek chub (*Semotilus atromaculatus*). *J. Exp. Biol.* **213**, 2284-2293.

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