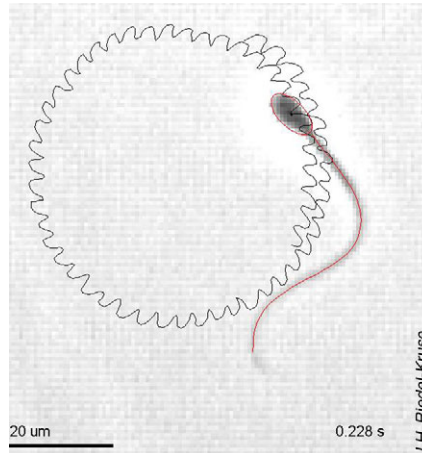


Inside JEB highlights the key developments in *The Journal of Experimental Biology*. Written by science journalists, the short reports give the inside view of the science in JEB.

Inside JEB

SPERM SWIMMING THEORY STANDS THE TEST OF TIME



When sperm cells are released, they have a simple objective: find the egg and do it fast. Benjamin Friedrich is a physicist who is fascinated by the relationship between the sperm's beating flagellum and the path it takes. 'How you get from the beat of the tail to the swimming path is pure physics of hydrodynamic forces,' says Friedrich. Friedrich explains that James Gray and G. J. Hancock proposed a theory of sperm motility, known as resistive force theory, which could predict a sperm's speed in *The Journal of Experimental Biology* in 1955. However, no one had successfully tested the theory by comparing it with an extensive data set and there had been some debate about the reliability of Gray's simple approach. Working with Frank Jülicher at the Max Planck Institute for the Physics of Complex Systems in Dresden, Germany, Friedrich realised that he and his collaborators, biologists Ingmar Riedel-Kruse and Jonathon Howard, were collecting the ideal data on sperm swimming to test the 50-year-old theory (p. 1226).

Filming bull sperm swimming in circles at 250 frames s^{-1} through a phase contrast microscope, Riedel-Kruse accurately measured the position of the beating flagellum and sperm head within less than 1 μm . 'Of course this cannot be done accurately by hand,' explains Friedrich, so Riedel-Kruse developed accurate computer algorithms to determine the position of the flagellum.

With 1 million datapoints for the flagellum's position in hand, it was time for Friedrich to begin testing the theory. Knowing the position of the flagellum and its instantaneous speed, Friedrich plugged these values into Gray and Hancock's theory to calculate the way in which the sperm head wiggled as it moved along its circular path. Amazingly, Friedrich's

calculations agreed remarkably well with the movies: his calculated sperm movements were identical to the sperm's movements in the movies.

Having used the theory to calculate the sperm's trajectory, Friedrich was also able to calculate a key parameter in Gray and Hancock's equations called the drag anisotropy ratio. According to Friedrich, whenever we move we push against something solid, like the earth, but sperm swimming in fluids have nothing solid to push against, so they have to rely on an imbalance between the friction forces that the flagellum experiences as it moves sideways and forward. The ratio of the two friction coefficients is the drag anisotropy factor and it must be greater than 1 for the sperm to move forward. Comparing his calculations with the movies of swimming sperm, Friedrich found that the perpendicular friction coefficient is 80% higher than the parallel friction coefficient, giving him a drag anisotropy factor of 1.8. Using this value, he was then able to calculate the radius of curvature of the sperm's circular path and found that it agreed perfectly with the movies. Gray and Hancock's theory had stood the test of time remarkably well.

Friedrich says, 'It is exciting that we can use physics to better understand biological questions. Of course sometimes physicists are ignorant of the nice details of a study and there can be clashes between the two cultures, but it is well worth the joint efforts of biologists and physicists to find out how biological phenomena work.'

10.1242/jeb.044552

Friedrich, B. M., Riedel-Kruse, I. H., Howard, J. and Jülicher, F. (2010). High-precision tracking of sperm swimming fine structure provides strong test of resistive force theory. *J. Exp. Biol.* **213**, 1226-1234.

STRANGE SHAPE AFFECTS SAND DOLLAR LARVAE SWIMMING

Most youngsters look a lot like their parents. They have the same number of arms and legs in roughly the same arrangement – but not sand dollar larvae. While their parents are disc shaped bottom dwellers, the shuttlecock shaped larvae bob around freely in the ocean. 'They are plankton that drift with the currents,' explains Tansy Clay from the University of Washington. Over the course of their development the larvae grow additional arms. Starting off with four, they develop another two and finally a total of eight before eventually settling on the seabed. And sand dollars are not the only larvae to take this strange shape. The larvae of several unrelated species are also shaped like shuttlecocks. 'So what is the purpose of



Tansy Clay

this crazy shape and why would different organisms independently evolve it?’ puzzles Clay. Intrigued by the larvae’s bizarre appearance, Clay and her supervisor, Daniel Grünbaum, decided to find out how the different larval stages swim. Knowing that their coastal water habitats are turbulent, the duo decided to focus on how the larvae fare in the flows in turbulent eddies (p. 1281).

According to Clay, previous attempts to understand how plankton move in turbulent eddies had represented them as simple spheres and ellipsoids. The calculations suggested that rounded plankton tilt in vertically circulating water so that they begin travelling horizontally toward downwelling water and are sucked down. Would the shuttlecock-shaped larvae suffer the same fate or would their strange morphology direct them into up-welling water?

The duo took a two-pronged attack: running computer simulations of the movements of all three larval life stages; and filming real larvae bobbing about in a tank. Basing the computer simulations on model larvae built from cylinders, Clay calculated how all three-life stages moved and found that they were directed into up-welling flows in mild turbulence found in a calm estuary. But as the turbulence increased, Clay’s calculations suggested that the four- and eight-armed larvae tilted and swam horizontally until they became trapped in downward plumes of water, while the intermediate six-armed larvae were tilted and drawn toward up-welling flows.

Clay admits that she was surprised that the differences in the larvae’s shapes had such a significant effect on their calculated movements. ‘I expected some differences but not that extreme,’ she says.

Turning to live larvae bobbing about in tanks, Clay generated vertical water flows in the middle of the tank by warming one side of the chamber and cooling the opposite side while she filmed the larvae’s movements in the central portion. Tracking the fluid movements with algal cells, Clay could see

that the four- and eight-armed larvae behaved as her simulations had predicted, travelling horizontally until they were engulfed in a plume of down-welling water. But when she looked at the six-armed larvae, they were doing something completely different: they didn’t move horizontally like the simulations. ‘It seems that they were resisting horizontal movement towards down-welling water,’ says Clay.

So the larvae’s strange shapes do change the ways in which they swim and could allow them to move selectively to different locations within the water column at different stages of development.

10.1242/jeb.044560

Clay, T. W. and Grünbaum, D. (2010). Morphology–flow interactions lead to stage-selective vertical transport of larval sand dollars in shear flow. *J. Exp. Biol.* **213**, 1281–1292.

LOGGERHEADS STAY AT SURFACE TO SOAK UP SUN



Fulvio Maffucci

Sandra Hochscheid is fascinated by loggerhead turtles. ‘I was always interested in what they do under the surface,’ says Hochscheid from the Stazione Zoologica Anton Dohrn, Italy. But when Hochscheid began hearing reports that the champion divers had been spotted on the surface on calm days, she was intrigued. Having spent most of the last decade tracking loggerhead diving behaviour with satellite technology, Hochscheid had never noticed the turtles taking extended breaks at the surface. ‘They only need a few minutes to recharge their oxygen supplies,’ explains Hochscheid, so why were the reptiles taking such long surface breaks? Curious to find out whether the anecdotes were true and, if so, why, Hochscheid and her Italian colleague Flegra Bentivegna, Abdulmaula Hamza from the Libyan Environmental General Authority and Graeme Hays from Swansea University, UK, decided to track loggerhead’s diving behaviour to see if they could find any evidence of the surfacing behaviour (p. 1328).

First the team had to find turtles that could be tagged with a sophisticated data logger that would send information back when the animals surfaced. Closely involved with a

rehabilitation programme that returns injured loggerheads to the Mediterranean, the team had access to eight juvenile turtles from the Stazione Zoologica’s Rescue Centre, as well as two turtles that had been caught in a net off the coast of Libya. Attaching the tracking devices to the tops of the animals’ shells, the team released them near the sites where they had been rescued, and waited for the data to start coming in.

Over a period of more than a year, the dataloggers contacted their satellites, which calculated the turtles’ locations on the surface, and then transmitted: how deep and long they had dived; the temperature of the water surrounding them; and the length of time they spent at the surface. ‘It was a really huge data set,’ remembers Hochscheid, but as she was analysing the data she realised that the anecdotes were true. The turtles did occasionally spend extended periods at the surface, ranging from tens of minutes up to a marathon 17 h on one occasion, with more than 80% of the visits occurring during daylight.

Looking closer to see if the behaviour was related to the turtle’s diving activity, Hochscheid noticed that the majority of stays at the surface occurred around noon, when the sun was at its highest, and that some of the turtles were diving much deeper than had been expected. ‘A few of the larger turtles were diving off the continental shelf and were going into very deep waters experiencing a 10°C temperature difference between surface and depth,’ says Hochscheid, who suspects that these animals remain at the surface to warm up after their cold deep dive and also to top up their vitamin D levels. But this couldn’t explain the night time surfacing events.

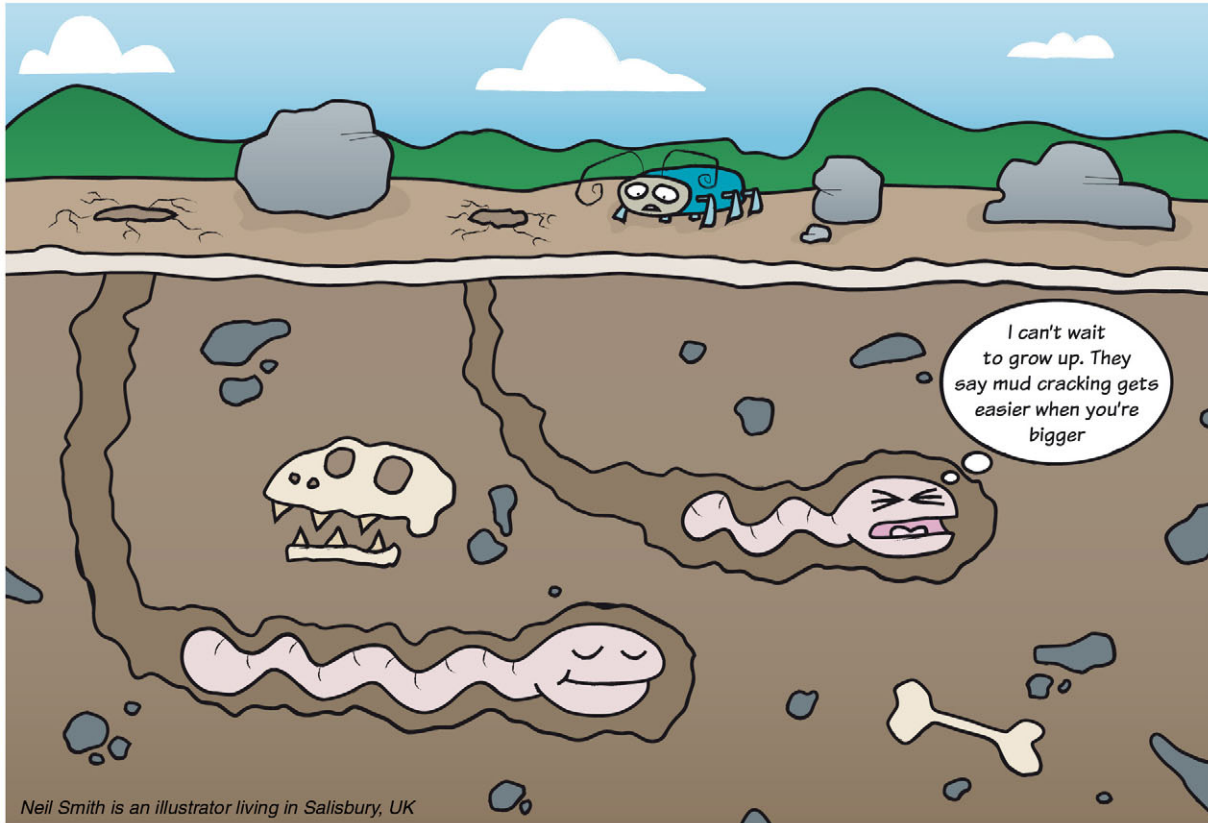
Scrutinising the duration of the dives that preceded the long nocturnal surface breaks, Hochscheid realised that some of the turtles were remaining submerged well after their oxygen stores must have run out. Knowing that turtles can extend the length of a dive by switching to anaerobic metabolism after exhausting their oxygen supply, Hochscheid suspects that the turtles may be clearing lactic acid – which accumulates during anaerobic metabolism – from their muscles during their long stopovers.

So loggerhead turtles seem to extend surface breaks for at least two reasons: to soak up the sun and get warm by day and to recover from anaerobic exercise at night.

10.1242/jeb.043901

Hochscheid, S., Bentivegna, F., Hamza, A. and Hays, G. C. (2010). When surfacers do not dive: multiple significance of extended surface times in marine turtles. *J. Exp. Biol.* **213**, 1328–1337.

WORMS BURROW BY CRACKING



Churning up sediments and redistributing nutrients and organic matter, burrowing marine worms are sometimes described as ecosystem engineers. But how do these creatures move through their sticky environment? Kelly Dorgan from the University of California Berkeley explains that *Nereis virens* burrow by driving cracks through sediments, but could other worms, which move in different ways, be doing the same? Curious to find out how pointy headed *Cirriformia moorei* polychaetes burrow, Dorgan and her colleague James Che collected the polychaetes from local mudflats and filmed the worms as they moved through mud-like gelatine (p. 1241).

Tracking the course of the front tip of *C. moorei*'s body, the duo could see the

polychaete lunge forward in four discrete phases. First the worm thinned and moved forward into the crack that had opened during the previous lunge. Having reached the end of the original crack it penetrated the fresh mud propagating the crack further. Once the worm had extended the crack as far as possible, it thickened its body, generating high stresses and widening the channel. Finally, the worm dragged the rest of its body forward into the crack as the head slipped back slightly. In essence *C. moorei* drives itself through the mud like a wedge cracking it apart, just like *Nereis virens* despite their different behaviours.

The duo also found that small *C. moorei* were blunter, thicker and varied their thickness more when cracking the

sediments open, and despite finding it harder than larger worms to penetrate sediments, the tiddlers were faster.

Considering the effects of worm populations on marine sediment structure, Che and Dorgan also suspect that smaller worms may be better at mixing sediments while larger worms may produce more permanent structural changes.

10.1242/jeb.044578

Che, J. and Dorgan, K. M. (2010). It's tough to be small: dependence of burrowing kinematics on body size. *J. Exp. Biol.* **213**, 1241-1250.

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