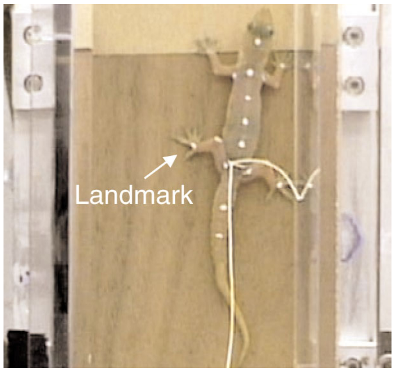
Inside JEB is a twice monthly feature, which highlights the key developments in the *Journal of Experimental Biology*. Written by science journalists, the short reports give the inside view of the science in JEB.

Inside JEB

DRIVING GECKOS UP THE WALL



It's a feature of many sun drenched holidays. You're sitting relaxing in the sun, you glimpse a swift movement out of the corner of your eye, but as soon as you look it's gone; lizards are notoriously nimble, and geckos must be the ultimate reptile gymnasts. Able to trot up vertical surfaces, the tiny reptiles seem to defy gravity. Fascinated by almost all aspects of the gecko's agile lifestyle, Bob Full from Berkeley, California, was intrigued by their remarkable vertical mobility. Even though the reptiles seem able to run against gravity, their climbing gait is almost indistinguishable from the style they adopt when scampering along the flat. How could that be? Puzzled by the conundrum, Full and Keller Autumn from Lewis Clark College, Oregon, decided to measure the forces generated by running geckos, whether they were scrambling up a wall (p. 260) or trotting on the flat (p. 249), to find out how geckos use very similar running styles, no mater which direction they're running in.

Working with Autumn and a team of dedicated undergraduates and gradstudents, Full put the tiny gymnasts through their paces (p. 260). Filming the lizards at 1000 frames s^{-1} as they charged up a wall fitted with a vertical force plate, the team were able to correlate the reptiles' lightning fast movements with the forces generated by their legs. Amazingly, the geckos trotted up the plate at break-neck speed, taking an astounding 30 steps every second. Full explains that the animals are moving so fast that he was sure they would decelerate substantially as their feet attached to the wall. But he was surprised when he saw that the geckos continued climbing at a near constant speed, even though the force they generated dropped to zero at the instant they stepped from one set of toes onto the other; instead of stalling, the lizards were propelled on by their own momentum at a colossal 0.8 m s^{-1}. The team was also able to see the geckos quickly detach one pair of sticky feet by peeling them off the surface at the same instant that they attached the other pair, a process taking 15 ms.

Analysing the forces generated by the gecko's fleeting feet, Full and Autumn realised that the instant the lizards' feet grabbed onto the wall, they pulled down while simultaneously pulling their legs inwards to get a good grip on the surface. While doing this, the team noticed that the tiny animals' heads pitched backwards, away from the wall as if they were about to fall off, but they recovered by pushing away from the wall with their rear legs while pulling their heads back in toward the wall with their front legs. Full says 'I've never seen anything like this before'.

But how did the geckos' horizontal trotting compare with their wall climbing antics? This time the team set the lizards scuttling along a track over a horizontal force plate, filming their every move with high speed video (p. 249). Sure enough, the geckos careered across the plate with the same trotting gait that they used to ascend the wall, but the forces they generated were completely different from the forces during their vertical ascent.

Firstly, the reptiles' fore legs were decelerating the animals' bodies while their hind legs mostly accelerated, despite trotting forward at a constant average speed. But the biggest surprise came when Full realised that instead of pulling their legs inwards, as they did when climbing, the horizontally trotting lizards were pushing their legs outwards. The pattern of forces was more similar to the pattern generated by running insects that bounce from side to side as they scamper along. And what is more, this bouncing movement probably allows the geckos to recover automatically when they stumbled. Full explains that this 'passive dynamic stability' is probably an inherent aspect of the lizard's musculoskeletal system, helping it to recover effortlessly whenever it loses its footing.

So, despite their remarkable visual similarities, climbing geckos are doing something that is very different from geckos running across open ground; in the gecko's case, looks have been deceptive.

10.1242/jeb.02042

Chen, J. J., Peattie, A. M., Autumn, K. and Full, R. J. (2006). Differential leg function in a sprawled-posture quadrupedal trotter. *J. Exp. Biol.* **209**, 249-259.

Autumn, K., Hsieh, S. T., Dudek, D. M., Chen, J., Chitaphan, C. and Full, R. J. (2006). Dynamics of geckos running vertically. *J. Exp. Biol.* **209**, 260-272.

UNIFYING LOCOMOTION

Picture by G. Nilsson.

Conferences are often a source of inspiration, but few can pinpoint the exact moment as well as Adrian Bejan. In September 2004, Bejan, an engineer from Duke University, was invited to a conference discussing allometric scaling in Ascona, Switzerland. He remembers that the meeting was stimulating and peppered with lively debate, but when he heard Jim Marden's talk about the recently identified force-mass relationship found in natural and man-made motors, Bejan realised that he could explain Marden's startling results with a simple physical law; the constructal law. Meeting over coffee after Marden's talk, the two quickly realised that they had struck up a remarkable collaboration. By the end of the three-day meeting, the pair had derived a theory that could account for several aspects of both flight and walking locomotion in respect to an animal's mass, but could they extend the theory to explain swimming too (p. 238)?

For engineers, the constructal law is one of the founding principles of design. In its simplest form it states 'for a flow system to persist, it must morph over time in such a way as to consume the least amount of energy while achieving the most' and a flow system can be anything from a river basin to herds of migrating animals. 'The constructal law's success in engineering is evident' says Bejan, 'engineers apply it intuitively'; but its application to biological design seems to have been less obvious. Applying the theory to various biological systems has allowed him to make a wide range of accurate physiological predictions, but could it explain the way the three major forms of locomotion scale relative to an animal's mass?

Bejan explains that he had already tackled flight from a constructal theory perspective before he met Marden. Considering the sum of energetic costs incurred by birds as they flap to overcome gravity, while propelling themselves forward against air resistance, Bejan optimised the system by minimising the sum of these losses and found that the speed and force output that he derived corresponded well with the values measured for birds and insects over a wide range of sizes. The constructal theory explained many aspects of flight locomotion.

Inspired by their new collaboration, Bejan and Marden began focusing their attention on running. Breaking running motion down into a set of horizontal and vertical movements, the team derived a set of equations based on vertical and horizontal energy losses and again minimised the sum of these losses as a function of size. The results were surprisingly good considering the simplicity of the theory. The team's calculated running speeds and stride frequencies showed a remarkable agreement with values measured from running animals.

But integrating swimming into the constructal theory of locomotion proved much harder. Bejan recalls that it took several months of brain wracking before the theory presented itself. The breakthrough came when the team began thinking of the way a fish moves through water. They realised that instead of lifting itself up through the water, the fish must push a fish-sized parcel of water over itself due to the incompressibility of water; 'the proverbial light bulb had gone on' recalls Bejan. As soon as the team began considering the fish from this new perspective, the constructal theory of swimming fell into place.

Bejan adds that 'zoology has known for decades that the relationship between speed and body mass is the same for flyers runners and swimmers, but this can no longer be treated as a coincidence'. The constructal theory seems to have unified three very disparate forms of locomotion.

10.1242/jeb.02041

Bejan, A. and Marden, J. H. (2006). Unifying constructal theory for scale effects in running, swimming and flying. *J. Exp. Biol.* **209**, 238-248.

ERRATUM

Phillips, K. (2005). Longterm heritability of basal metabolic rate. *J. Exp. Biol.* **208(24)**, ii.

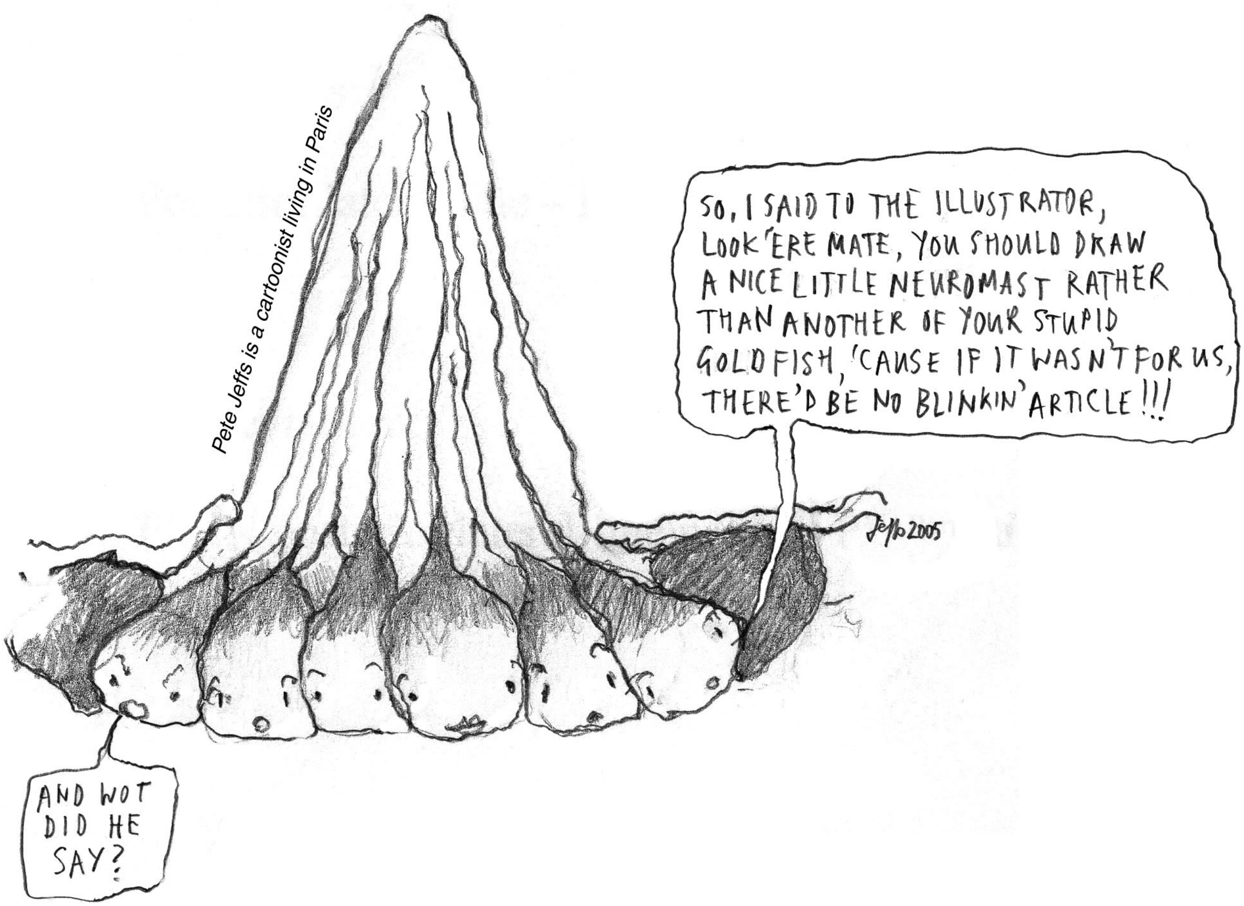
In both the on-line and print versions, the title of the article 'Longterm heritability of basal metabolic rate' published on-line in Inside JEB on 2 December 2005 was incorrect.

The title should have been 'Longterm repeatability of basal metabolic rate'.

We apologise for this error.

10.1242/jeb.02043

LATERAL LINE NEUROMASTS DETECT COMPLEX WATER MOTIONS



Pete Jeffs is a cartoonist living in Paris

Scything through the water, fish keep track of passing currents with a sensory organ known as the lateral line. Composed of mechanosensory cells that detect water speed and pressure gradients, the lateral line helps fish negotiate a path through their watery domain. Jacob Engelmann and his colleagues wondered whether these sensory organs could also detect vortices generated in water by obstacles and other creatures. Using a combination of particle image velocimetry and neurophysiological methods, Engelmann, Boris Chagnaud and Horst Bleckmann visualised vortices passing along the fish's side while recording neural responses from the lateral line and found that the mechanosensory cells responded to the direction that the water swirled in the vortex. The lateral line seems to detect vortices (p. 327).

Given that every flick of a fin generates spinning vortices, Engelmann explains that several groups have suggested that 'detection of vortex rings may be of importance for prey detection' for fish with a taste for other fish. Having shown that the lateral line is capable of detecting these gentle swirling movements, it is possible that fish may hunt by vortex detection.

10.1242/jeb.02039

Chagnaud, B. P., Bleckmann, H. and Engelmann, J. (2006). Neural responses of goldfish lateral line afferents to vortex motions. *J. Exp. Biol.* **209**, 327-342.

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