INSIDE JEB

Arm swinging saves energy

Arm swing reduces the metabolic cost of human running. Photo credit: Nicole E. Look.

Have you ever tried running without swinging your arms? It's not easy. Each step jars and it feels like hard work: but is it? Christopher Arellano, from Brown University, USA, says, 'We know from the literature that arm swinging plays an important role in balancing the motion of the swinging legs.' But it wasn't clear how the upper body movement affected the metabolic cost of running. And when Arellano and his thesis advisor, Rodger Kram, from the University of Colorado, Boulder, USA, looked into the literature to find out whether the metabolic effects of arm swinging had been measured, they found few studies and those that they did find did not agree. With the jury out, Arellano and Kram decided to embark on a thorough study of the impact of arm swinging on the metabolic cost of running (p. 2456).

Fortunately, when Arellano initiated the study he was based in Boulder, which is home to a community of dedicated runners: 'It is never a problem to recruit people', he laughs. Having calculated that he required 13 runners to generate sufficient data, Arellano selected eight men and five women who were all committed runners. Inviting each runner to the lab, Arellano asked them to run normally on a treadmill for 7 min as he measured their oxygen consumption rates and the amount of carbon dioxide that they exhaled. Then he asked them to run without swinging their arms by holding the arms loosely behind the back, crossing the arms across the chest, and holding the hands on the top of the head. 'I think everyone conceded that the most challenging run was the one with the hands on the top of the head,' chuckles Arellano, who recalls the runners complaining about how tired their arms were at the end of the session.

Having measured the athletes' oxygen consumption rates and carbon dioxide production, Arellano then calculated the metabolic rates of each runner when they were swinging the arms and holding them in all three positions. Comparing the four metabolic rates for each individual, Arellano and Kram could see that swinging the arms reduced the runners' energy costs by 3% (relative to when they held their arms behind their backs). Arm swinging also saved an impressive 13% compared with when they held their hands on their heads. And when Arellano analysed the athletes' shoulder movements, he could clearly see that the runners had compensated for the loss of the counterbalancing swinging arms by increasing the amount that they swivelled the upper body. 'Whether they knew it or not, they all compensated in a very similar way by increasing the amplitude of their torso rotation', recalls Arellano.

Swinging the arms clearly saves energy for runners, and helps to minimise the amount that we rotate the body while swinging our legs, which led Arellano and Kram to wonder whether the metabolic benefits of arm swinging outweigh the cost of carrying the limbs. Explaining that they were interested in how metabolic energy is partitioned between different aspects of an activity, Arellano says, 'The arms weigh about 10% of the body, so if we took them away we could hypothetically save 10% of the metabolic cost of running, but at the same time you wouldn't have any mass to counteract the swinging of the legs, so running would be more difficult to stabilise.' And Arellano is keen to follow up on two of the runners whose running costs were unimproved by moving their arms. 'Either they are not getting the benefit of arm swinging or somehow they modified their running style to keep the metabolic costs the same', he says.

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Arellano, C. J. and Kram, R. (2014). The metabolic cost of human running: is swinging the arms worth it? *J. Exp. Biol.* **217**, 2456-2461.

Kathryn Knight

Clingfish grip reduced by algae

Northern clingfish (*Gobiesox maeandricus*). Photo credit: Petra Ditsche.

Life in the intertidal zone is rough, with waves continually pounding anything that chooses to live there. Some intertidal residents huddle in crevices for protection, while others simply anchor themselves to the rocks to ride out the surge. Northern clingfish (*Gobiesox maeandricus*) grip on to rocks with a suction disk on their bellies: 'They have an impressive ability to stick to substrates with a huge variety of roughnesses', says Petra Ditsche, from the University of Washington, USA. However, rocks on the shore are rarely pristine. They are usually coated in a carpet of slippery microorganisms and algae, which made Ditsche and her colleagues Dylan Wainwright and Adam Summers wonder how the slimy layer would affect the tiny fish's cling power (p. 2548).

But before the trio could test out the fish's grip, they had to produce a series of consistently rough surfaces, varying in grain size from silt to fine gravel, so Ditsche turned to sandpaper. 'I had used moulds of sandpaper in former studies', she explains, adding that casting the moulds in the same material also eliminated material property differences. And when she ran out of course grades of sandpaper to test, Ditsche resorted to

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gluing different grades of fine gravel to cardboard to produce the roughest moulds. Then she hung multiple samples of each surface in the sea at Friday Harbor Laboratories for 6 weeks until they were covered in algae and other microorganisms, ready to test the impact on the tenacious little fish.

Back in the lab, Ditsche teamed up with Wainwright to measure the force required to tug fish ranging in mass from 1.5 to 15 g free from the clean surface, and saw that the fish found it harder to stick to the smooth surface than to the fine-grained surfaces. They suffered the greatest failure in performance when the grain size increased from 500–1000 μm to 1000–2000 μm, although the largest fish fared better than the smallest fish, which couldn't hang on to anything coarser that 1000 μm. They also found that fish with small discs (up to 13 mm diameter) could not stick to anything coarser than a 269 μm grain-size surface, while the larger fish with 34 mm diameter discs were able to secure themselves firmly to the coarsest surfaces.

Next the team tested the effects of the slimy coating on the fish's grip, and was impressed to see that the fish could cling on to the fouled smooth and rough surfaces with impressive forces of up to 14–15 N, which is 150 times the body weight of the fish. And even though all of the fish could still cling to the fouled surfaces, the suction forces that they could generate were reduced, affecting their attachment to the finest surfaces by over 20% while their ability to cling on to the 269 μm surface only fell by 6%.

Considering the material properties of the microorganisms and algae that had grown on the test surfaces, the team suggests that the slim component of the microorganism film acts as a lubricant between the fish and their rocky resting place, reducing friction between the suction cup and the rock by preventing the tiny hairs that line the circumference of the disc from interlocking with the rock surface. Ditsche says, 'The growth of biofilm or other fouling organisms on the original substrate can have a considerable impact on the attachment of aquatic animals, and fouling has to be taken into account when considering the attachment of aquatic animals in general.'

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Ditsche, P., Wainwright, D. K. and Summers, A. P. (2014). Attachment to challenging substrates – fouling, roughness and limits of adhesion in the northern clingfish (*Gobiesox maeandricus*). *J. Exp. Biol.* **217**, 2548-2554.

Kathryn Knight

p53 not effective in hibernation

Golden-mantled ground squirrel (*Spermophilus* [*Callospermophilus*] *latealis*). Photo credit: Frank van Breukelen.

When the temperature begins to fall and the days draw in, some animals opt for hibernation to conserve energy, which means cutting back on many costly metabolic processes. According to Peipei Pan and Frank van Breukelen, from the University of Nevada, Las Vegas, USA, the key process of transcription – where genes are transcribed from DNA to messenger RNA (mRNA) prior to translation into proteins – is extremely costly, so it is virtually arrested in hibernating animals. However, proteins that control the process of transcription (transcription factors) move in and out of the nucleus while an animal is hibernating, which puzzled Pan and van Breukelen. What could these transcription factors be doing when transcription in the cells of hibernating animals is essentially shut down? The duo decided to investigate the regulation of p53, a key protein that regulates many essential cellular processes, in hibernating golden-mantled ground squirrels to find out how transcription factors function in hibernating tissue (p. 2489).

'p53 is a really cool protein. It sits at the crossroads of a lot of decision-making in the cell', says van Breukelen, so he and Pan monitored several of the numerous processes that regulate the activity of this key protein in the livers of the hibernating animals. Selecting five proteins that are known to regulate the p53 protein, Pan monitored the mRNA or protein levels for each of the regulatory proteins in the squirrel's liver and found that they were consistent with activation of the protein. 'If a known positive regulator increased… then that should mean activation', explains van Breukelen.

Pan and Michael Treat then investigated a whole slew of other cellular processes. They identified p53 in the nucleus of winter squirrels that were torpid and briefly aroused from hibernation, confirmed that p53 bound DNA in the nucleus (and could therefore presumably activate DNA transcription) and even showed that p53 could recruit RNA polymerase – which transcribes DNA into RNA – to genes. However, when Pan measured the mRNA levels in the torpid squirrels of genes that p53 is known to activate and initiate transcription of, she was amazed to see that instead of increasing the mRNA level of those genes, the expression levels were significantly reduced. Even though all of the other indicators suggested that p53 was active and would regulate transcription in the hibernating animals, it clearly was not. p53 is not an effective transcription factor in hibernating ground squirrels.

Explaining that he sees torpor as a mess, where imprecise regulation of cellular processes culminates in energetic savings, van Breukelen says, 'The best way to make sure a machine doesn't use energy it not to slow it down, but rather to break it', and this is how he sees the process in hibernation. However, he goes on to point out that the 'mess' must be repaired when an animal arouses from torpor, and he says, 'I see the arousal process… as being where the fascinating biology happens.'

van Breukelen also warns that it would not have been possible to reveal this disruption to the transcription factor's activity in hibernation if they had focused only on one or two events in the cascade that leads to transcriptional activation. 'It sounds simple, but investigators should not make assumptions about function based on other systems that are functioning in a different context', he says, urging others to take a more holistic approach when attempting to untangle the complex network of events that regulate cellular physiology.

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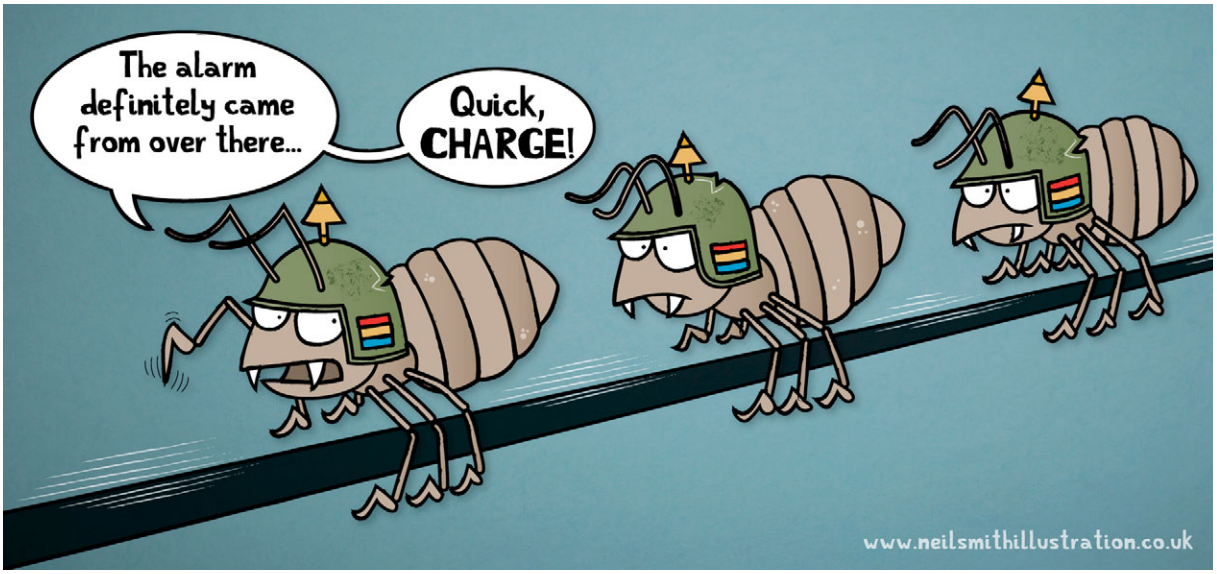
Pan, P., Treat, M. D. and van Breukelen, F. (2014). A systems-level approach to understanding transcriptional regulation by p53 during mammalian hibernation. *J. Exp. Biol.* **217**, 2489-2498.

Kathryn Knight

Termite legs sense super-short time differences



It's an unconventional form of communication, but when their mound home is under attack, termite soldiers pound their reinforced heads against the ground to sound the alarm. Felix Hager, from the Ruhr University Bochum, Germany, explains that termites detect the alarming signal with vibration-sensitive organs in their legs, called chorodontal organs. But it wasn't clear whether the insect's nervous system was sensitive enough to detect the infinitesimal delay between the vibration arriving at each leg to give them a sense of which direction the sound was coming from. 'In the nests of *Macrotermes natalensis*, vibrational alarm signals are propagated at 130 m s^{-1},' says Hager and colleague Wolfgang Kirchner, meaning that the insects would have to be able to detect vibrations arriving at each of the legs within 0.2 ms of each other. Was this possible (p. 2526)?

First the duo tested how soldiers and worker termites responded to simulated alarm vibrations, and confirmed that worker termites flee while soldiers turn to attack. Then they tested how much of a delay the termites could resolve between vibrations arriving at their legs. First they set up two PVC platforms separated by a 1 mm gap and connected each to a loud speaker to produce the alarm signal vibrations. Next they placed five termite soldiers with their legs straddling the gap and set the platforms vibrating after delaying the vibration of the second platform by less than a millisecond. Altering the delay from 0.29 to 0.09 ms, the duo was impressed to see that the soldiers turned toward the platform that vibrated first, just like soldiers in a real attack, and the insects could detect time differences between the vibrations arriving at their legs of only 0.2 ms. So termite nervous systems are sensitive enough to respond to the super-short time differences between vibrations arriving at their legs, which will allow them to decide how to react in the event of an attack.

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Hager, F. A. and Kirchner, W. H. (2014). Directional vibration sensing in the termite *Macrotermes natalensis*. *J. Exp. Biol.* **217**, 2526-2530.

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