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Inside JEB

FIGHTING SHAPED HUMAN HANDS


Dave Carrier

The human hand is a finely tuned piece of equipment that is capable of remarkable dexterity: creating art, performing music and manipulating tools. Yet David Carrier from the University of Utah, USA, suggests that the human hand may have also evolved its distinctive proportions for a less enlightened reason: for use as a weapon (p. 236).

Carrier recalls that the idea occurred to him during an impassioned discussion with fellow biomechanic Frank Fish about sperm whales. Explaining that he had published a paper suggesting that the whales might use their spermaceti organs as battering rams, Carrier says 'Frank didn't buy the argument and at one point he raised his fist and said, "I can hit you in the face with this, but that is not what it evolved for."' A light went on in Carrier's head. Sure, the human hand evolved for dexterity, but he adds, 'You could manipulate the proportions of a chimp hand in ways that would enhance manual dexterity, but they would not necessarily end up with the proportions that we have.' Maybe there was more to Fish's challenge than met the eye.

According to Carrier and colleague Michael Morgan, modern chimpanzees have long palms and fingers with a short thumb, while the human palm and fingers are much shorter and the thumb longer and stronger. Carrier explains that this squat arrangement allows us to clench our hand into a fist when we fold the thumb across the fingertips; however, chimp fingers form an open doughnut shape when curled. Could the tightly packed human fist provide internal support – buttressing – to the digits to protect them from damage during combat? In addition, Carrier wondered whether curling the fingers into a fist could allow punching men to deliver a more powerful blow (increase the peak force of an impact) than slapping with the open hand. Carrier and Morgan decided to find out whether hands are more effective when balled into a fist or wielded in a slap.

'Fortunately, Michael had a lot of experience with martial arts and he knew people who were willing to serve as subjects', Carrier recalls. Asking the athletes to thump a punchbag with their hands in a range of shapes (from open-handed slaps to closed fists) using various delivery styles (over arm, sideways and head on), Morgan and Carrier measured the force of each impact. However, they were surprised to see that the punch did not deliver more force per blow. 'In terms of the peak forces or the impulse, it did not matter whether the subjects were hitting with a clenched fist or open palm', Carrier says.

Next the duo tested whether buttressing the hand by curling the fingers and thumb stiffens the structure. They asked the martial arts experts to roll their hands into variations of the fist shape – two with the thumb extended sideways – and then push the first joint of the index finger against a force transducer to measure the rigidity of the knuckle joint in the presence and absence of the buttressing thumb. Impressively, the knuckle joint was four times more rigid when supported by the thumb. And when the duo measured the amount of force that the athletes could deliver through the fist surface of the index and middle fingers, they found that the presence of the buttressing thumb doubled the delivered force by transmitting it to the wrist through the metacarpals (palm bones) of the thumb and the index finger.

So our short, square hands are perfectly proportioned to stiffen our fists for use as weapons and allow us – well, males predominantly – to deliver powerful punches without incurring injuries.

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Morgan, M. H. and Carrier, D. R. (2013). Protective buttressing of the human fist and the evolution of hominin hands. *J. Exp. Biol.* **216**, 236-244.

Kathryn Knight

SANDFISH SWIM EFFORTLESSLY TO BURROW

Scincus scincus's popular name – sandfish – really does say what it does on the tin. These reptiles literally swim through sand and they are perfectly happy to remain submerged for the majority of the day to avoid heat and predators. Daniel Goldman, from the Georgia Institute of Technology, USA, says, 'There has been a lot of work looking at swimming in fluids, flying, and running on relatively flat rigid hard ground, but there has been much less work done on the movement of organisms on and within materials like sand that can behave as fluids and solids.' Explaining that submerged sandfish wriggle through sand using a technique similar to that of *C. elegans* nematodes, Goldman adds that no matter how fast the lizards move through the

material or how deep they travel, they always weave their bodies along the same characteristic wavy line, 'Which was very surprising for us', he says. Intrigued by the lizard's ability to penetrate more densely packed sand without altering their swimming style, Goldman and student Sarah Sharpe embarked on an ambitious series of experiments where they filmed the submerged animals while simultaneously measuring their muscle activity patterns to find out how the lizards control sand-swimming (p. 260).

Carefully inserting minute electrodes into muscles along the lizards' bodies – to record muscle electrical activity – and cautiously wrapping the wires into tight bundles to prevent the animals from tangling, Sharpe filmed the swimming sandfish moving through sand with high-speed mild X-rays while measuring their muscle activation. In addition, Sharpe wanted to find out how the lizards coped in tightly and loosely packed sand, so she blew air through the sand before each run, allowing it to resettle and produce densely or loosely packed pristine sandbeds for each run. However, even though the lizards were extremely cooperative – burying as soon as they were released – Sharpe had no control over their direction once submerged. 'They don't always go in a straight direction. Many times they turned through 180 deg and swam backwards, so we had to depend on luck [to get straight swims]', she remembers. 'It took years to get everything working correctly', recalls Goldman.

Analysing the painstakingly collected muscle activation patterns, Sharpe and Goldman could see that the muscles were activated more strongly as the sandfish penetrated deeper into the sand. 'We found travelling waves of muscle activation moving down the body and we believe that the sandfish are producing more muscle force as they go deeper', says Sharpe. So instead of altering their wavelike swimming style, the lizards pressed harder on the sand as it became denser.

However, when the duo investigated the muscle electrical activity patterns as the lizards speeded up, they found that they animals were able to move at much higher speeds without increasing their muscle activity and exerting more force on their surroundings. Goldman suspects that this is because sand is a granular fluid. He explains, 'Friction is speed insensitive and the collection of speed-independent forces [as grains rub each other] is also speed insensitive. So, the animal experiences the same resistive forces from its environment, whether it is swimming at a high or low frequency [speed]'. In other words, the sandfish thrust sand out of the way with the same force regardless of their speed. And when Yang Ding calculated the mechanical cost of moving the swimming lizards through sand (the amount of energy needed to sweep sand out of the way) by mathematically exaggerating their movements, he found that the lizard's natural wriggling motion allows them to glide through the sand while expending the least energy, making sandfish remarkably effective burrowers.

10.1242/jeb.083758

Sharpe, S. S., Ding, Y. and Goldman, D. I. (2013). Environmental interaction influences muscle activation strategy during sand-swimming in the sandfish lizard *Scincus scincus*. *J. Exp. Biol.* **216**, 260-274.

Kathryn Knight

HUMAN IGF1 EXTENDS MOZZIE LIFESPAN

The scourge of malaria is a grim threat hanging over much of the developing world. Faced with the disease's intimidating statistics, Shirley Luckhart, from the University of California, Davis, USA, and her collaborators have a goal: to produce mosquitoes that are immune to transmitting the deadly parasite. According to Luckhart, when mosquitoes dine on an infected human, in addition to filling up on malaria-spiced blood, the insect consumes a cocktail of human hormones. Having already found that a dose of human insulin reduces the insects' lifespan and having successfully designed malaria-proof mosquitoes by activating the same cellular processes that are triggered by insulin, Luckhart and student Anna Drexler decided to look at the effect that another close relative of the insulin hormone – insulin-like growth factor 1 (IGF1) – would have on the insect and its ability to transmit the lethal infection (p. 208).

First, Drexler – with colleagues Eric Hauck and Elizabeth Glennon – tested the effects of human IGF1 on mosquito cells in a test tube to find out whether the insect cells carried the essential cellular machinery that is necessary for the cells to respond to the human hormone, and she was relieved to find that the insect cells did respond. However, isolated cells are much less complex than an intact mosquito, so Drexler next had to test how the insects reacted to IGF1-spiked blood meals, and the first thing that she investigated was whether the hormone could survive intact in the insect's gut.

Adding radioactive IGF1 to a blood meal, Mark Brown and Andrew Nuss, from the University of Georgia, USA, analysed how much of the intact hormone remained undigested in the mosquito's gut and were pleased to find that it was still intact 24 h later. They then checked for radioactivity in other parts of the mosquito's body, and found that the hormone had also been transported to the thorax and head. Finally, Drexler tested to see whether the same cellular machinery that had been activated in the test tube cells was triggered in the intact mosquitoes, and sure enough, she saw similar signalling cascade proteins being activated.

Having confirmed that the mosquitoes could respond to the human hormone, Drexler moved on to test the physiological effect that IGF1 had on the insects by feeding the hormone to them in blood meals at concentrations found naturally in healthy humans. Monitoring the mosquitoes' survival rates, Drexler was amazed to see that the insects that had been fed the lowest IGF1 concentrations lived 23% longer than those that had been fed a hormone-free blood meal. So, instead of shortening the insect's life expectancy, as insulin had done, IGF1 was extending it. And when she investigated the effect that the hormone had on the number of cysts – which produce the next infectious parasite life stage 10 days after consuming an infected meal – on the insect's gut, Drexler found that the number of cysts was drastically reduced. Normal levels of human IGF1 could actually reduce the infectiousness of an insect bite.

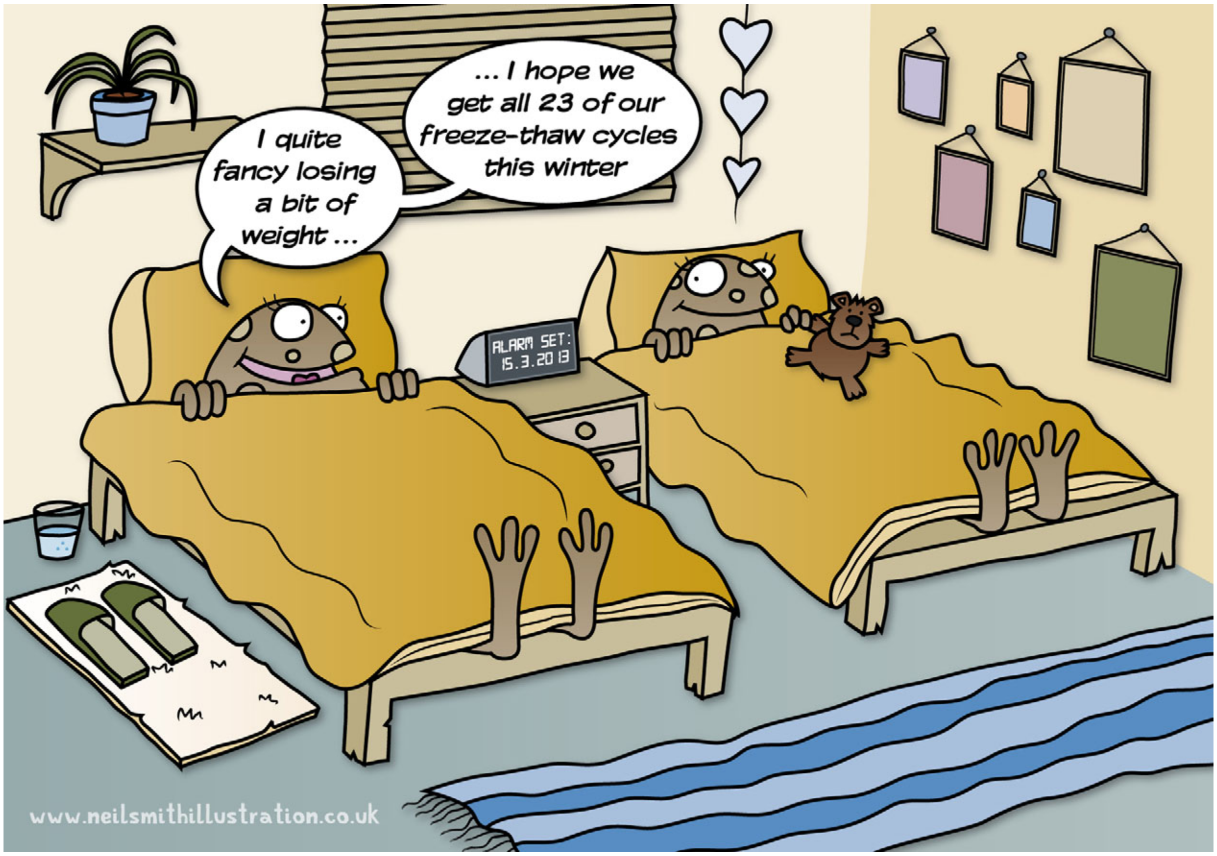
However, Luckhart explains that human IGF1 levels drop dramatically during malaria infection, so Drexler tested the effect that these lower IGF1 levels in a blood meal from an infected human had on the number of infectious cysts, and this time the number increased. 'This trend suggests that as the severity of a malaria infection increases, parasite transmission also increases, and this could have important epidemiological consequences in the human population', Luckhart says, although she and Drexler are optimistic they can alter the effect that IGF1 has on parasite infectivity to produce a mosquito that is even more malaria proof.

10.1242/jeb.083741

Drexler, A., Nuss, A., Hauck, E., Glennon, E., Cheung, K., Brown, M. and Luckhart, S. (2013). Human IGF1 extends lifespan and enhances resistance to *Plasmodium falciparum* infection in the malaria vector *Anopheles stephensi*. *J. Exp. Biol.* **216**, 208-217.

Kathryn Knight

FREEZING COSTS FROGS DEAR



Wood frogs have a rather unconventional approach to surviving winter: they simply freeze solid. Flooding their bodies with glucose – which protects delicate cell structures from being shattered by ice – the frogs emerge in spring unscathed by a process that would prove fatal for most other creatures. Brent Sinclair, from The University of Western Ontario, Canada, his students, and Ken Storey from Carleton University, Canada, explain that freezing frogs have to burn precious lipid stores to convert glycogen into glucose, but no one knew just how much of these valuable reserves they consumed to pull off the freezing stunt (p. 292).

Freezing and thawing frogs as they measured the amount of carbon dioxide produced by the amphibians to find out how much energy the animals consumed, Sinclair and his colleagues found that the frogs increased CO_2 production to 104 ml at 1°C (just before freezing) before drastically increasing it to 565 ml when they froze solid. And when the team recorded the amount of CO_2 produced when the frogs thawed, they found that this too incurred a metabolic cost as the animals produced another 564 ml pulse of CO_2. The team says, 'We interpret these increases in metabolic rate to represent the energetic costs of preparation for freezing, the response to freezing and the reestablishment of homeostasis and repair of damage after thawing.'

But how much energy do real wood frogs – buried beneath insulating snow and leaf litter during the harsh Canadian winter – expend to emerge unscathed in spring? Burying temperature data loggers in a wood near Ottawa, the team recorded 23 freeze–thaw cycles and then calculated the amount of energy that frogs in the vicinity would have consumed. Realising that the frogs only spent 6–8% of the winter frozen, the team estimates that a 7.1 g frog consumes 0.28–0.37 g of its lipid stores and 0.05–0.12 g of carbohydrate while weathering the winter. The team adds that the high cost of freezing and thawing probably outweighs the energy saved while frozen, suggesting that the frogs probably evolved their inventive freezing strategy for reasons other than energy conservation. However, they warn that climate change could cause hibernating frogs to run out of fuel by exposing the frogs to more frost if snowfall occurs later in the season.

10.1242/jeb.083733

Sinclair, B. J., Stinziano, J. R., Williams, C. M., MacMillan, H. A., Marshall K. E. and Storey, K. B. (2013). Real-time measurement of metabolic rate during freezing and thawing of the wood frog, *Rana sylvatica*: implications for overwinter energy use. *J. Exp. Biol.* **216**, 292-302.

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