Researchers study the biomechanics of locomotion

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Rodger Kram, a faculty member in the integrative physiology department and an expert on human locomotion, has a fond place in his heart for kangaroos. A few decades ago he and colleagues measured the gait and metabolism of hopping kangaroos, and more recently took a look at their other mode of movement—grazing on all fours for food.

Oops, make that all fives. Because a new study involving Kram and researchers at Simon Fraser University in Burnaby, Canada and the University of New South Wales in Sydney, Australia showed that when kangaroos are grazing—which is most of the time—their tail becomes a powerful fifth leg, providing as much propulsive force as their front and hind legs combined.

"We went into this thinking the tail was primarily used like a strut, a balancing pole, or a one-legged milking stool," explains. "What we didn't expect to find was how much power the tails of the kangaroos were producing. It was pretty darn surprising."

As far as hopping goes, kangaroos are aided by extremely long Achilles tendons, said Kram. As a result, they can hop faster without consuming metabolic energy more rapidly. "Their tendons act like springy pogo sticks," he explains. "In effect, it is impossible to tire out a kangaroo while it hops over level ground."

In a 1986 study, Kram was part of a team that measured the energy expenditure of red kangaroos as they hopped on a moving treadmill at varying speeds. One kangaroo especially seemed to enjoy it, jumping onto the treadmill as soon it was released from its cage and waiting expectantly for the machine to be turned on.

Once researchers saw the importance of elastic energy storage in kangaroo tendons, says Kram, they turned their attention to how human legs use tendons as springs. "The springy legs of kangaroos inspired the first carbon prosthetic legs for running," he explains. Kram and Assistant Professor Alena Grabowski of integrative physiology now are investigating how to optimally "tune" springy leg prostheses to minimize the energy consumption of human runners with leg amputations.

What's the best way to get a kangaroo to hop onto a treadmill? Bribe it with sweets, of course, Kram says.

From elephants to ostriches

Over his career, Kram and his colleagues, including dozens of students, have studied the locomotion of a number of creatures, from elephants and llamas to ostriches and beetles. They took a closer look at several creatures that are slow or awkward walkers like giant Galapagos tortoises, which can weigh more than 350 pounds.

"They sprint at an 8-hour-per-mile pace, not an 8 minute-per-mile pace," he says. At that rate, a mosey by one of these reptiles from Boulder to Denver down U.S. 36 – a roughly 20-mile journey – would take about a week lumbering nonstop day and night.

"We first quantified how poor their biomechanics were," he explains. "But when we studied their much smaller cousins, the box turtles, we found that they are actually very energetically efficient despite their biomechanics." It turns out that tortoises have a plethora of "slow-twitch" muscle fibers that contract slowly but keep working for a long time, allowing the shelled reptiles to consume little energy while supporting their body weight and propelling themselves forward.

But the locomotion studies by Kram and his colleagues invariably circle back to humans. "As we age, we slow down and do not move as smoothly," says Kram. "And our maximum aerobic capacity diminishes. So efficient walking becomes more and more challenging if we want to remain independent, community-dwelling citizens."

Studies of the waddling locomotion of penguins, it turns out, provided the stimulus for Kram and his team to analyze how people who are extremely obese walk. "Penguins are the opposite of tortoises – they have what appear to be great biomechanics but use a lot of metabolic energy per unit of body weight," Kram explains. "It turns out that it is the short legs of penguins that cost them energy, not their prodigious body fat percentage."

When Kram and former CU-Boulder doctoral student Ray Browning, now a faculty member at Colorado State University, turned their attention to people who were obese, the two predicted that, based on biomechanics, they would use a lot of extra energy.

"But we've been repeatedly impressed by how people who are obese still manage to walk with nearly the identical efficiency per unit of body mass as lean people," Kram says. "We admire, but still don't understand, the underlying grace with which obese people move. So studying other species provides both inspiration and insight into the gait of humans with and without physical challenges."

Walk 'young' again

In 2012 and 2013 Kram and then-CU-Boulder doctoral student Jason Franz conducted a series of experiments on how the human ability to walk diminishes with advanced age. They found older people walking over level ground tended to rely on more on their gluteus maximus muscle in the buttocks and much less on the calf muscle.

Kram and Franz invented a special, force-measuring treadmill to help train older people to generate calf muscle forces just like young people. "Basically, the machine provides feedback so we can teach them to 'walk young' again," explains Kram. The two scientists applied for a patent on the novel concept along with CU Tech Transfer Office and are now working with a treadmill manufacturer to commercialize the idea.

But back to the kangaroos, which Kram and colleagues showed could increase their metabolism by 50 times during exercise. In addition to acting as a fifth limb, the kangaroo tail also acts as a dynamic, springy counterbalance during hopping, and boosts balance when male kangaroos grab each other by the chests or shoulders, then rear back and boot each other in the stomach in an attempt to assert dominance.

"I'm envious of kangaroos," says Kram, a competitive master runner in the mile and 1,500 meters. "When they hop faster, they don't use energy at a faster rate. The have the ability to move faster and not get tired, the ultimate dream of a runner."

Provided by University of Colorado at Boulder

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