Tread lightly. The zebra-tailed lizard's toes may explain why this species can outrun ghost crabs (*below*) on soft sand.

BIOMECHANICS

Crab's Downfall Reveals a Hole in Biomechanics Studies

The melding of materials and movement to better understand locomotion gets a boost from physicists studying the properties of granular materials

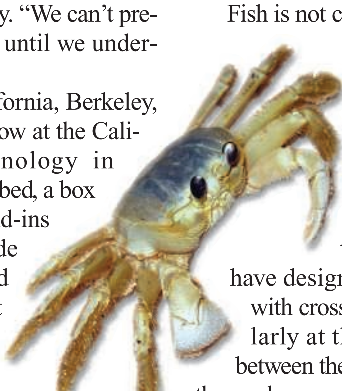
PHOENIX, ARIZONA—When it comes to running on sand, the ghost crab is an Olympic champion. With legs that are a blur to the naked eye, *Ocypode quadrata* scoots up to 2 meters per second on hard-packed sand. But soften up the sand a bit, and the gold medal instead goes to the zebra-tailed lizard, an animal that spends little time on the grainy material. This surprising observation, reported earlier this month here at the annual meeting of the Society for Integrative and Comparative Biology, comes courtesy of physicist Daniel Goldman of the Georgia Institute of Technology in Atlanta.

Goldman has jumped into the field of biomechanics by employing a device physicists have long used to examine granular materials. That's allowed him to study how animals move over different kinds of surfaces, an approach that Goldman and others feel has been neglected to a large extent. "It's nice to see practical and theoretical applications of granular physics applied to an organismal biomechanics problem," says Andrew Biewener, a biomechanicist at Harvard University. "It creates an entirely new field of investigation," which will advance both basic biology and robot engineering.

Until now, most researchers have studied how animals walk, run, trot, and otherwise move using hard, nonskid platforms. "When we studied forces, the last thing we wanted was to have slippery surfaces," says Catherine Loudon, a biomechanicist at the University of California, Irvine. And this approach has proved useful, as researchers have made progress analyzing how muscles and tendons make different gaits possible (*Science*, 21 January 2005, p. 346).

But in the wild, organisms must contend with mud, gravel, and ground littered with debris. Sand can be particularly challenging, as its grains give way briefly underfoot, transforming the surface from a solid to a virtual liquid. Goldman wants to understand how organisms deal with this complexity. "We can't predict how animals will move until we understand the substrate," he says.

At the University of California, Berkeley, Goldman and Wyatt Korff, now at the California Institute of Technology in Pasadena, built a "fluidized" bed, a box of glass beads that were stand-ins for sand. The bed's underside has a porous membrane, and by pumping air at different speeds up through the membrane, Goldman can change how tightly packed the beads are, thereby controlling the properties of the "sand." More air results in looser packing and, eventually, a surface much like quicksand. Aerated enough, the bed turns into a fluid. The method is "extremely brilliant," says Frank Fish, a biomechanicist at West Chester University in Pennsylvania.



Goldman and his colleagues chased ghost crabs, geckos, and various lizard species down a sand-filled track and across the bed, filming the animals as they traversed hard, soft, and "liquid" sand. In addition, he and Korff dropped wires attached to rods into the sand to determine the mechanical requirements for locomotion in sand of different consistencies.

As expected, the ghost crab zoomed across the hard-packed sand. But in soft sand, its eight legs sank in, and the crab trudged along at about 40 centimeters per second. That's about the speed of the gecko, which is adapted for living in trees, not on beaches. "We didn't think there would be such a big difference," Goldman says. The Mohave fringe-toed lizard, another sand dweller, also got bogged down: Its speed dropped by 10%. "Being specialized for sand doesn't necessarily mean better performance" on all forms of sand, Goldman reported.

The big winner on the softer sands was the zebra-tailed lizard. It left the ghost crab in the dust, maintaining at least a 1.5-meter-per-second pace, even in quicksand. This species lives in a varied environment, traveling through brush and on rocks, gravel, and, occasionally, sand; therefore, Goldman expected that it would lack any special adaptation that would enable it to excel on any one surface. But the zebra-tailed lizard didn't sink, and "it seems to use feet as a buffer against the substrate," Goldman said. The lizard has extremely long, gangly toes, and Goldman discovered that it spreads the toes wide as they hit the sand and then curls them up as it lifts the foot. He suspects that sand caught between the toes causes the sand to stop flowing such that it supports the lizard's weight and allows the animal to push off into the next step.

Fish is not convinced that long toes are the secret to this lizard's success. "I don't think they understand enough about the dimensions of the feet and how they interact with the sandy environment," he says.

Goldman is addressing those interactions. He and Korff have designed an artificial "foot": a rod with crossed wires attached perpendicularly at the end. They vary the angle between the wires and drop the "foot" into the sand, measuring how far it sinks. "The penetration depth depends on the angle" between the individual wires, Goldman reported. "It shows geometry can be important in your foot."

Understanding the differences between how the ghost crab and zebra-tailed lizard move could help engineers make better robots, which for the most part stop dead in sand. "You want to have robots that can run around on all surfaces," says Loudon. For that reason, "it's of great importance to understand how animals can [handle] such different surfaces."

–ELIZABETH PENNISI

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