Photo: John Carnemolla/© iStockphoto.com

BUILT for SPEED

BY NINA SCHALLER

With the aid of face-to-beak observation, a visiting ROM researcher uncovers the secrets of an exceedingly efficient marathon runner

Opposite: A feral ostrich racing through the African steppe. Although flightless, this bird is actually "airborne" for 70 percent of the time it's running at high speed.

Huge eyes, elegant strides, a flurry of fluffy wings. The largest bird on earth stands imperiously before me and, without warning, her beak dives to my level from a height of 3 metres, stealing the cap off my head. The thief runs for the hills. I give chase, but quickly embrace its futility; within seconds, I'm left in the dust.

We humans are quite good on our feet—top marathon runners cover 42 km in just over two hours. But we don't come close to matching the performance of the ostrich. At a steady 60 km per hour, this 150-kg giant can cover the same distance in one-third the time, and with top speeds exceeding 70 km per hour, it can actually run faster than some of its avian relatives can fly.

These big birds are not just fast. Bernhard Grzimek, director of the 1959 award-winning documentary *Serengeti Shall Not Die*, points out that no other animal runs with the endurance of the ostrich. Its unparalleled combination of speed and stamina allows this bird to cover great distances to find fresh grazing pasture or quickly outdistance hungry hyenas.

It was in 2002, during a volunteer stint at the Frankfurt Zoo, that I became fascinated by the ostrich's ability to leave everyone behind. I wanted to find out how they did it. Relative to size, ostriches require only two-thirds of the predicted amount of metabolic energy to run a given distance. This suggests that unknown mechanisms are in play.

A few existing studies described some of the ostrich's locomotor components—there were anatomical descriptions and some lab studies of ostriches running on treadmills (no, they weren't spotted at the local gym!—the birds ran on machines specially designed for their size and weight). But nobody had explored both form and function. My study would examine skeletal and muscular structures and employ modern biomechanics to discover what makes this bird a marathon superstar. My third methodology, though, was the most exciting. To closely observe live ostriches in a way that ensured reliable data gathering, my best solution was hand-raising the ostriches myself (see "Fowl Play," page 29).

SPEED

First I looked at speed. I used the ROM's skeleton collection to compare the length of the ostrich's leg to those of other ground-dwelling bird species, including the chicken-sized roadrunner and the 50-kg emu. Not surprisingly, ostrich leg architecture is "top-of-its-class" in both requirements for reaching high velocities—long step length and high frequency of steps. Ostriches have the longest legs comparatively, capable of achieving incredible 5-metre stride lengths when running. And their muscle mass is concentrated high on the thigh bone and hip compared to the other species, making the swinging portion of the leg, below the knee, comparatively the lightest, giving the ostrich a high step frequency.

Right: In terms of speed, the two-toed ostrich beats the three-toed emu hands down. The emu walks "flat-footed" while the ostrich tiptoes with an elevated "heel." This creates an additional leg joint, decreases friction surface, and increases leg length to achieve optimum speed.

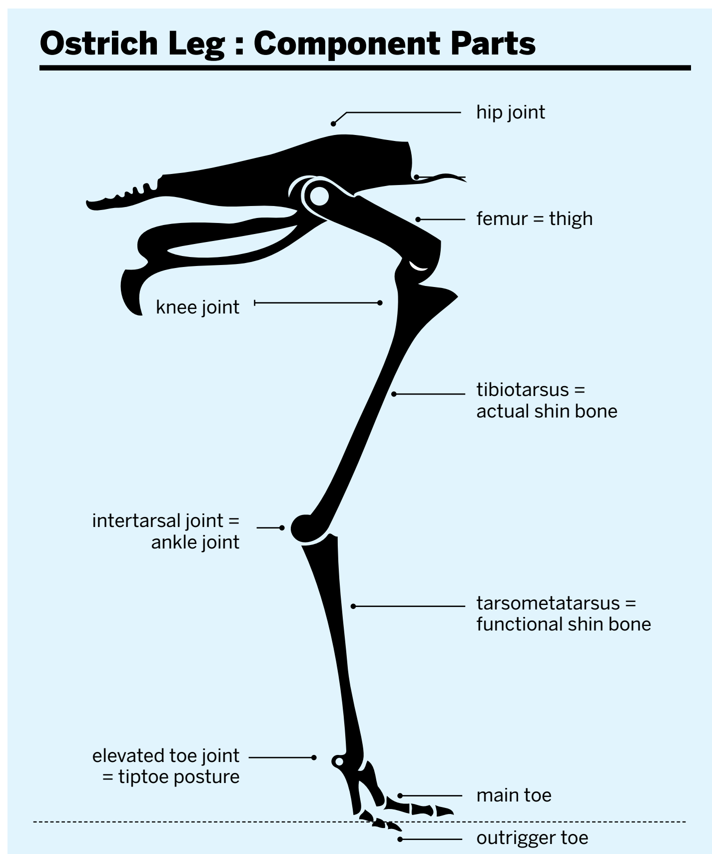


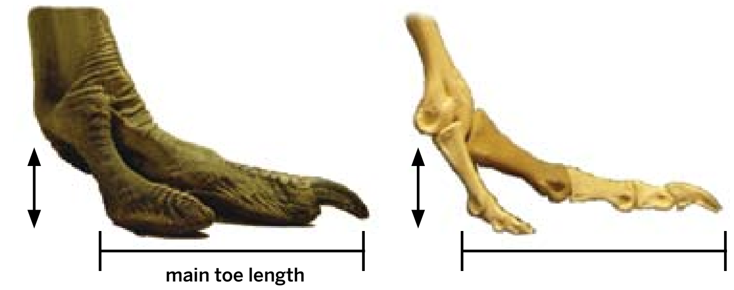
Photo: Nina with ROM ostrich, James David Smith. Illustration, Nina Schaller. Emu, John Carnemolla; ostrich, mauhorng, both © iStockphoto.com

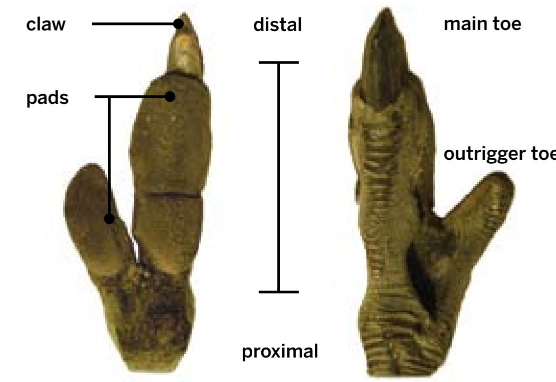
ENDURANCE

Next I looked at endurance. In humans, a wide range of joint motion allows us to climb trees or ballet dance, but this flexibility comes at a cost. When humans run, muscle power is diverted to stabilizing sideways joint movements, increasing our overall energy requirements. I suspected that ostriches had a more efficient way of controlling range of motion.

Unlike actively powered muscles, ligaments can limit joint motion passively in much the same way that a corset does. I filmed my ostriches from various angles, and measured the range of motion in the live birds. I then measured how far I could move a dissected ostrich limb that had the muscles and tendons removed. The range in the live and dissected limbs was nearly identical, proving that ligaments are the main elements that guide an ostrich's leg through its stride. This frees up muscle power to be devoted to forward propulsion.

While I was manipulating the dissected limbs, I noticed something else that hadn't been recorded before. I had to overcome some resistance when trying to flex the ankle joint—an unexpected finding in a lifeless limb devoid of muscles. When I released the joint, it automatically snapped back to an extended position. Here again, it seemed that ligaments could be keeping the bird's leg extended passively. To test this theory I exerted pressure on the leg until the ankle joint collapsed into a flexed position. It required 14 kg of downward force—28 kg of weight that an ostrich standing on two legs would not have to support actively, again freeing up energy for forward motion.





The right "foot" of an ostrich (black arrows indicate elevated toe joint).

Above, left: Average standing position with "outrigger" toe abducted.

Above, right: Toe skeleton.

Left: Top and bottom views.

Left: An ostrich walking overground with the right "foot" forward. The inset depicts the corresponding load-distribution profile recorded with a pressure plate. Red indicates areas of very high load, dark blue indicates minor load.

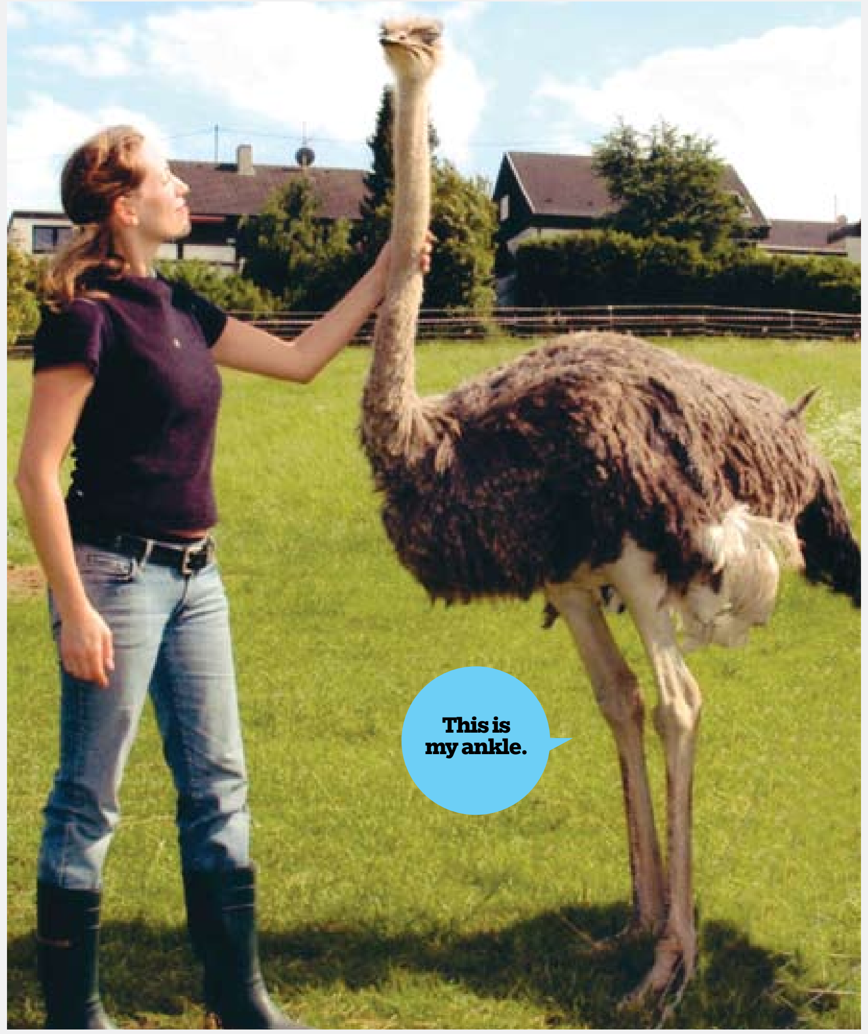
Illustration and pressure plate profile, Nina Schaller. Ostrich walking, Casarsa/© iStockphoto.com

WHERE THE RUBBER MEETS THE ROAD

Decreased friction on the ground is another way of increasing energy efficiency. This is why the wheels of a *Tour-de-France* bicycle are considerably narrower than those of Granny's old clunker and why properly inflated car tires improve gas mileage. Toe positioning is the main strategy animals use to decrease surface friction. Over the course of evolution, the previously five-toed horse, for example, now gallops only on the toenail of its middle finger—or hoof.

A similar evolution is seen in the ostrich. Its ratite relatives (other large flightless birds), including the Australian emu and South American rhea, possess three toes while all other bird species have four. The ostrich is the world's only two-toed bird. It is also the only bird to walk on tip toe.

The combined reduction in surface contact of having only two toes and using a tiptoe posture is impressive: compared to emus and rheas, the ostrich's plantar surface—the part of the foot touching the ground—is 60 percent smaller relative to size. So the ostrich loses very little energy through friction.



Comparative Anatomy

While humans are plantigrade—meaning that we place our entire foot on the ground when we walk or run—birds are digitigrade—they use only their toes. In birds, the bone between ankles and toes is much longer than in humans, and serves an equivalent function to our shin bone. The bird's ankle joint is up at knee level, which explains why a bird seems to flex its "knee" backwards. A bird's actual knee joint, hidden under plumage, is permanently flexed and connects to the hip joint via a short, horizontal thigh bone.

I wondered if examining exactly how ostrich toes interact with the ground could tell me more. This had never been studied in live birds and there was no established method of investigation. I came up with the idea of using a pressure plate, a device commonly used by orthopedists to analyze pressure distribution in human feet. Fortunately, I was able to persuade my ostriches to walk over the plate, which provided high-resolution real-time recording of how pressure transitioned over the ostrich "foot" as it walked. I found that, like shock absorbers, the soft soles of the toe evenly absorb high stresses. This increases the ostrich's grip on the ground and protects the toe bones. I also discovered that the big toe supports most of the ostrich's body mass, while the smaller toe acts as an outrigger, compensating for loss of balance. While walking, the claw of the big toe barely contacts the ground, but it exerts pressures up to 40 kg/cm² (about the force of a full bottle of champagne falling on your toe) when the bird runs. The claw digs into the ground like a hammered spike to ensure reliable grip at 70 km per hour—maximum speed with minimal energy, ideal for endurance running on level ground of the African savannah.

Ostrich Facts

Watchtower of the Steppe
With a height of 3 metres and excellent eyesight, ostriches are the early-warning system of the African savannah. Grazers, such as zebras and gazelles, have learned to keep an eye on nearby ostriches. If one starts running, it's often best to follow suit.

Eyes on the Prize
At 5 cm in diameter, the ostrich's eye is not only bigger than its brain but is the largest of the terrestrial vertebrates—larger even than that of the elephant, which can weigh close to 7.5 tons.

Finding Ms. Right
To bump up their sex appeal during mating season, male ostriches blush a bright red on beaks, necks, and legs. They also engage in "feats of strength" during vigorous kick-boxing tournaments. Admiring hens demur to courtship by the victors.

Lords of the Dance
As part of their courtship ritual, males perform an impressive flamenco with wild wing fluttering, neck snaking, and a penetrating song of subsonic "booms."

Revenge of the Top Hen
In addition to having a primary hen, a male ostrich takes two or more secondary mates, and all females lay eggs among several nests—a strategy that increases genetic diversity. A single nest can contain up to 40 eggs, but only 20 can be successfully incubated. An unexplained instinct allows the top hen to identify her own eggs and she discards alien surpluses first to reach the optimum number.

Keeping a Low Profile
Ostriches don't really bury their heads in the sand. But to "disappear" from view, the grey-brown female ostrich sometimes lays her head and neck on the ground, keeping perfectly still.

Shell Game
Ostrich eggs are the largest of bird eggs and have the most robust shells. Unlike any other bird, ostrich parents carefully pre-crack soon-to-hatch eggs with their breast bone.

Photo: Nina and Tiffy, Gisela Löffler. Ostrich foot, Nina Schaller. Bare foot, webphotographeer/© iStockphoto.com

Fowl Play: How I Trained My Avian Co-workers

To begin raising my own ostriches, I obtained three 10-week-old chicks from a small ostrich farm in western Bavaria, a place I knew allowed the young hatchlings to run free in the yard. I would be bringing them to a perfect outdoor "bird cage" near my home in Heidelberg provided by ostrich enthusiast Jürgen Gass. The huge grassy enclosure had abundant space for running, a gigantic sand bath for preening, and plenty of trees and shelters. Using young ostriches in my study was essential—I needed to gain their trust, which allowed me to trust them: a kick from a full-grown ostrich is powerful enough to kill a lion.

The irrepressible nature of the birds became immediately apparent. As I drove them from their birthplace to their new home in a cube-van—with no barrier separating driver from cargo—the chicks did not sit down and enjoy a tranquil ride. There was squealing, hair-pulling, and radical destruction of my sunglasses.

When the birds settled into their new home, each day I engaged them in playful training, observed them, and simply spent time with them. Before long, individual personalities emerged. The calmest and friendliest was Tiffy, named after the Big Bird character in the German edition of *Sesame Street*. She would stick close to me even if the other girls ventured off to pluck leaves or befriend the older ostriches. Frida shared an opinionated state of mind with her namesake, artist Frida Kahlo, and sometimes tried to boss me and the older birds around by hissing at us. I would immediately yell "Stop it!" "Hissing back" was important: one does not want to give the illusion of control to a 2.5-metre-tall bird. But I would then pet her on the back and we were friends again. Cheeky Zora, with her reddish plumage, resembled the character Red Zora, an audacious red-haired heroine from a well-known German tale. She would sneak up behind me and beak-pinch my ear, then race away. She also loved to "zip" the zipper of one of my sweaters, sometimes for several minutes at a time.

During the first two years, my young ostriches spent the nights protected in their shelter. At sunrise, I would open the gates and be rewarded with an amazing spectacle: The Dance of the Ostrich. The birds would race out, zigzagging throughout the enclosure with elaborate pirouettes, curtseys, and effusive wing flutter. The Dance, accented with extreme turns at high speed—often using me as the pylon—was a mix of morning exercise, coordination development, and unbridled fun.

After these gymnastics, breakfast was served: a diet of wild-grass and special grain-mineral mix. During daily training sessions, I moved throughout the enclosure with the ostriches in tow, acclimatizing them to me and the training ground in preparation for my experiments. To attract their attention, I carried a rubber-chicken squeeze toy. For extra fun, we played "beak-ball." I would toss the squeaky toy into the air for a "player" to snatch, and, with a whip of the bird's head, the chicken again took flight, terrorized by a swirl of striding legs and outstretched necks. The game was on!

Despite their charm, ostriches are difficult to train. "Sit" or "fetch" simply will not happen with these independent animals. The most I could hope for was having them perform their natural behaviours in a place I had determined. Over the years, though, I was able to establish a series of rudimentary signals. A high trilling sound (similar to that of young ostriches) compelled them to come to me. During episodes of mock-combat, which could become rather ferocious, a loud shout of "Stop!" would disentangle the birds.

It was also important to consider one's wardrobe. Consistently wearing blue—a neutral colour not confused with competitors in the ostrich brain—increased the birds' confidence. Once another employee fed the ostriches and, despite our warnings, he wore black coveralls—the colour of male ostriches. Maxi, Jürgen's dominant male, took offence and ran the poor man over. No kick, just a solid bulldozing resulting in three broken ribs. Blue is good.

When my birds reached 3 years of age, I began to introduce them to the "experimentation corridor." The nosy ostriches easily followed me inside to see whether "upright biped" had found something of interest. After awhile, I would allow only one ostrich at a time into the corridor while I walked or ran within it. This became a game to them, but when they got bored, I would fetch the Red Bucket, a very important tool that signalled "food delivery."

The time I spent with Tiffy, Zora, and Frida was the most exciting and rewarding part of my PhD studies. I often recall the first months when I would sit in the straw, easing them to sleep with fluffy heads cradled in my lap, and cold winter days when they would lift their wings to let me warm my hands on their thighs. Now, as semi-retired science graduates, they enjoy leisurely days, they have the run of the roost, and they've started laying their first eggs.

Upper left: Face-to-beak observation at very close range provides more smile than insight.

Right: While a canary is happy bathing in a spoonful of sand, this wouldn't do for a beauty-conscious bird 25,000 times larger. Wings are used to shower the body with the granular skin-and-feather scrub.

Ostriches and History

Africa 10,000 to 5,000 BCE
Ancient Saharan rock carvings depict these birds, which are still hunted for their meat, skin, and feathers. The petite Kalahari Bushmen manage this dangerous task by perfectly mimicking their prey in posture, behaviour, and costume.

Ancient Egypt
The ostrich was codified in the Egyptian hieroglyphic system and appears in ancient texts and frescoes. Because of its symmetry, the ostrich feather was considered a symbol of justice, and became the ensign of Maat, the goddess of truth.

Ancient Greece
Greek explorers, who encountered ostriches on their journeys through the Middle East, provided the modern scientific name for this bird: "*Struthio camelus*," meaning "camel-footed sparrow"—a satirical juxtaposition.

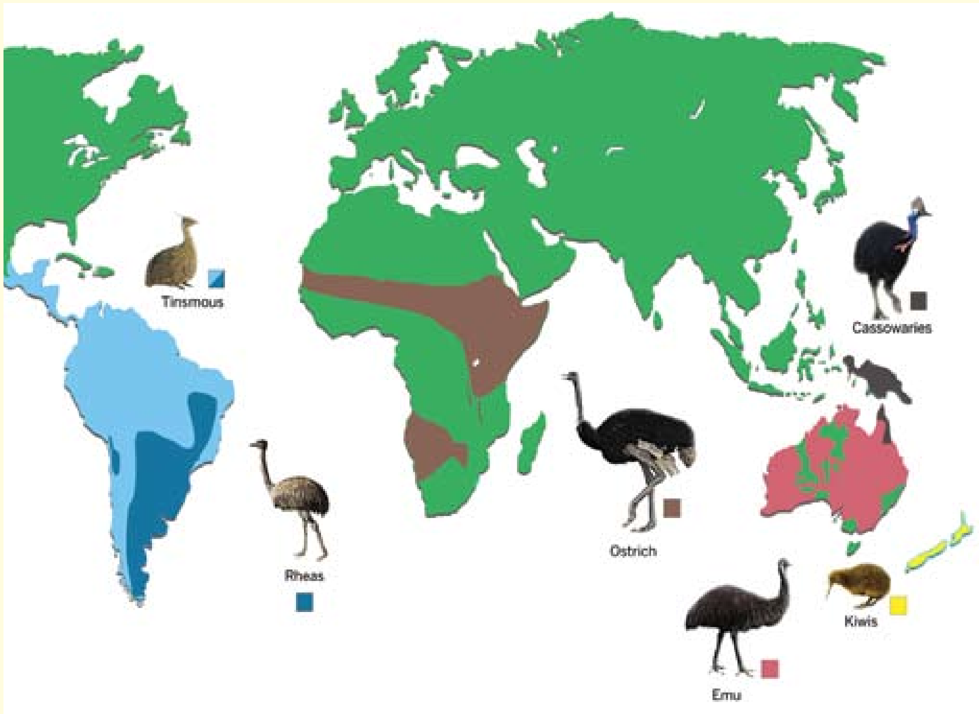
Ancient Rome
In Rome, the sense of humour was darker. Ostriches served as the opening act in the Circus Maximus before the real stars—the gladiators—took the stage. The birds were beheaded for the masses to enjoy the spectacle of the headless animals scurrying in confusion.

Medieval Europe
Hundreds of years before the first zoos were established, travelling merchants profited handsomely from exhibiting live ostriches. The birds' imposing presence inspired many innkeepers to name taverns after them.

Rococo Era to 19th century
Marie-Antoinette, the French Queen and fashion maven, used ostrich feathers on her headdress for a time. Naturally, this *accessoire de mode* became *de rigueur* for the aristocracy of 18th-century Europe.

Photos: Tiffy and Nina, Gisela Löffler. Sand bath, Nina Schaller.

Come Sail Away



How the Ostrich Got to Africa

Until a few thousand years ago, ostriches weren't found solely in Africa as they are today, but lived throughout Asia and at the edges of Europe. In fact, the oldest ostrich fossil found in Africa is only 20 million years old, but molecular evidence indicates that this bird diverged from its closest relative more than 60 million years ago. The current theory poses that the ostrich's ancestor rafted on India when the supercontintent Gondwanaland broke apart. Once India collided with Asia, the bird walked throughout the Old World, eventually ending up in Africa, via the land link with Arabia.

The ostrich's closest living relatives, the rheas, emu, cassowaries, kiwis, and tinamous, are found in the New World or islands of the southern hemisphere—and it's likely that they, too, rafted away on their own pieces of the former Gondwanaland.

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PRACTICAL APPLICATIONS

This study has gone a long way to further our understanding of how the ostrich runs so fast for so long. Now that we understand these biomechanical strategies, perfected over 60 million years of evolution, we may be able to adapt them in modern technologies such as bipedal robotics, suspension systems, and joint-stabilization engineering. Already, some of my findings have inspired developers of "intelligent" human prostheses to adapt features of ostrich legs and toes, which may allow amputees a wider range of function and maneuverability.

Left: Hot-footed and hot-headed, Zora is the cap thief. Although a woollen hat suits this bird nicely, ostriches can endure very low temperatures: -10°C at night is not uncommon in some regions of Africa.

THE NEXT STEP

Since the ostrich is far too heavy to fly, scientists have long assumed that its wings are used only as a parasol for shade-seeking chicks and to make a powerful impression during courtship. But in the years we worked together, my avian subjects revealed that during swift turns, the birds rapidly extend one wing, which works like an air-rudder to assist in changing direction. And when coming to a sudden stop from breakneck speeds, an ostrich spreads both large, densely feathered wings to engage a "brake chute" similar to those used by dragsters. It will be intriguing to see what turns up from my next study—which looks at wing function.

I WANT MY CAP BACK!

Armed with what you've learned about the swift ostrich, you may have suspected that I—a comparatively short-legged, big-footed biped—was not likely to retrieve my head covering. As a gracious provider, though, Nature tends to balance each shortcoming with an advantage. *Homo sapiens sapiens*'s two handy forelimbs and impressive brain can be of utmost help in tricky situations. In my case, I had to come up with something that would a) attract more attention than my cap and b) render the turbo-prankster approachable. My secret weapon was the thief's favourite snack: corn. I loudly filled the Red Bucket with yellow gold and casually sauntered back to the scene of the crime. There stood the thief, already waiting at the gate, beak wide in anticipation, my cap carelessly discarded on the ground. Warm head, full belly. Tie game. ○

ACKNOWLEDGMENT

My interdisciplinary research included collaborations with ornithologists at the ROM, morphologists at the Senckenberg Research Institute, Frankfurt, and the University of Heidelberg, and biomechanics specialists at the University of Antwerp.

Photo: Ostrich with cap, Nina Schaller. Illustration, Oliver Haddrath.