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A Model Walker

Fashioning a Tinkertoy® contraption that walks but can't stand

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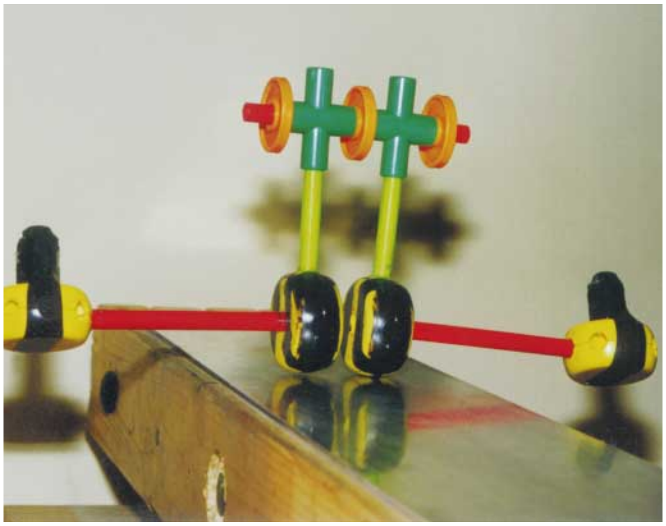


Coleman

Although unstable when still, a toy walker wobbles down a ramp.

Watching the first, faltering steps of a child learning to walk serves as a handy reminder of the intricacies of human locomotion—and of the astonishing ease and rapidity with which people become accomplished pedestrians.

Somehow, people manage to balance a top-heavy, upright body on two thin legs, achieving a marvelous stability whether standing still, stepping over obstacles, or walking briskly down the street.

That stability arises from the interaction between the body's motor and sensory systems and its mechanical structure, as embodied in its arrangement of bones, muscles, tendons, and ligaments.

The common view has been that maintaining the balance necessary for walking is largely a matter of neurological control. Now, researchers are beginning to suspect that the mechanical design of the body might be as important as the signals the legs receive from the brain.

As part of an investigation of the role that mechanical structure plays in walking, researchers have built a simple, two-legged toy that, powered only by gravity, totters down a gently sloping ramp. With no control system, it walks but can't stand upright in any position when stationary.

Engineering graduate student Michael J. Coleman of the Human Power, Biomechanics, and Robotics Laboratory at Cornell University designed and constructed the walker from plastic Tinkertoy® parts and a few other components. He and Cornell mechanical engineer Andy L. Ruina describe the toy walker in a report scheduled for publication in PHYSICAL REVIEW LETTERS.

Coleman's contraption is not only a novel toy, it is also a mechanical model that may provide new insights into how people walk. Despite years of study, "we don't know much about human walking," says mechanical engineer Arthur D. Kuo of the University of Michigan in Ann Arbor. "Passive walking models seem to have a lot of characteristics that are similar to human walking."

Such findings may eventually lead to improved artificial legs and better techniques for correcting neuromuscular ailments. They could also help researchers improve the design of walking robots.

Coleman's walking toy was inspired by the pioneering work of Tad McGeer, originally at Simon Fraser University in Burnaby, British Columbia, and now at the Insitu Group in Underwood, Wash.

About a decade ago, McGeer made the radical proposal that much of the stability and balance associated with walking comes not from the brain but from basic physics. Noting the resemblance between the motion of a pair of legs and that of a pair of swinging pendulums, he constructed machines—some with straight legs and others with hinged joints to serve as knees—that could walk down a shallow slope all by themselves.

Lacking motors, sensors, or computers, McGeer's walkers had a graceful, steady gait remarkably similar to that of a person. He described the resulting movement as passive-dynamic walking.

The walking machines built by McGeer could only stand upright when one leg was forward and the other back. While walking, the machines would momentarily settle into such a position with each stride. Therefore it's possible that the walker's stability while moving depended in some way on its stability while standing still.

In designing and investigating mechanisms that vaguely mimic human geometry and that walk without control, Ruina and his coworkers have been extending McGeer's research with a combination of mathematical analysis, computer simulation, and experiment. In developing a mechanically complete model of walking, their emphasis has been on the role played by such physical factors as gravity, inertia, and contact.

The team succeeded in developing a downhill walker that could not only stride at a steady pace but, depending on the slope, also limp or take steps at irregular intervals in a chaotic stagger down a ramp. Like McGeer's models, however, this walker was stable in certain positions when standing still.

Coleman took on the challenge of designing a mechanism that could walk but not stand. His aim was to demonstrate that passive balancing can occur during movement without the need for spinning parts such as gyroscopes or flywheels.

Coleman started with the simplest possible three-dimensional model: two straight legs hinged at the hip and shod with rounded disks. Computer simulations taking into account the structure's geometry, the mass of its parts, the slope angle, the force of gravity, and other factors, however, failed to generate stable walking.

To get a better sense of the distribution of mass and the range of movements possible for the model in the simulations, Coleman assembled an analogous device out of plastic Tinkertoy® parts. It had two straight legs, rounded feet, and balance rods extending outward from its ankles.

"Playing—with no hopes of success—we placed the toy on a ramp," Coleman and Ruina recount. "Surprisingly, it took a few serendipitous, if not very steady or stable, steps."

A little tinkering produced a device that walks remarkably reliably and steadily (see box). Placed facing downhill on a ramp, tipped to one side, and then released, the walker wobbles from side to side as its legs alternately swing and make contact with the ground. When one foot strikes the ground, it sticks and rolls until the other foot makes contact. The trailing foot then takes to the air to repeat the cycle.

Indeed, Coleman's walker moves somewhat like a person who has stumbled but instinctively knows where to place a leg to avoid falling. In this case, that capability comes entirely from the walker's mechanical features, not from any control signals sent to govern its actions.

Why Coleman's toy walker works still isn't fully understood. .

The original computer simulations did not predict that the structure would be able to walk, so the model is missing some crucial element. Coleman is now working with Ruina and Mariano Garcia at Cornell to improve the model by varying potentially important physical factors such as hip spacing and type of contact between foot and surface.

"To construct a much more stable [and humanlike] device, we feel sure that we are going to have to rely heavily on simulations," Coleman notes.

Several researchers have already duplicated the device and obtained comparable results. Theoretical physicist John Rundgren of the Royal Institute of Technology in Stockholm followed Ruina's instructions, with a few minor modifications, and assembled a walker that could take up to seven steps down a ramp, covering a distance of about 30 centimeters.

Mathematician Louis Piscitelle and coworkers at the U.S. Army's Natick (Mass.) Research, Development, and Engineering Center also found construction and operation of the device straightforward. "It would easily lock onto a stable gait down the incline," Piscitelle says.

Coleman and Ruina had used a flexible brass strip, fastened with electrical tape, to cover the holes along the circumference of each spool serving as a foot. Piscitelle looked into how the smoothness of its feet affected the walker's motion. In his experiments, the device walked successfully with a thin foam pad covering the brass strip, but it stalled when the holes were simply filled in rather than covered.

Coleman has also been studying footing and contact. Subtle changes may make a difference in how well the device functions, he says. For example, the springiness and temporary deformation of the metal strips on the feet could play a role.

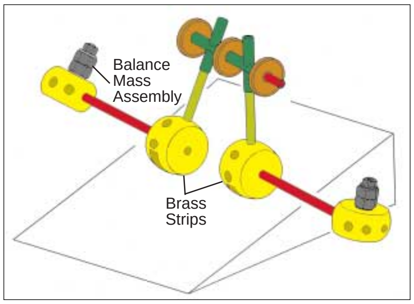
They don't know whether the metal strips are essential, but "we haven't found any other design that works," Coleman says. Other complications include such factors as vibrations of the entire walking structure caused by the elasticity of the Tinkertoy® rods.

For Piscitelle and others, the discovery of a novel example of uncontrolled walking helps clarify the physics needed to develop a complete model of human locomotion. The Army, for example, would like to use such a computer model to determine the effects of equipment, such as a heavy, bulky backpack, on a soldier's performance.

Once passive walkers are perfected, small amounts of power could be added to robotic devices to enable them to walk on level ground, and simple control mechanisms could be introduced to improve stability. "There is certainly an enticing opportunity to build [two-footed walking] machines of unprecedented efficiency and dexterity," McGeer says.

The development of a device that is unstable when standing still yet stable while walking represents fundamental progress, Rundgren says. It's certainly becoming clear that two legs can walk a surprisingly long way without guidance from an active brain.

Building a walker



Coleman's walker can be assembled from color-coded plastic Tinkertoy® parts, as shown in the diagram. Each leg is made from a yellow spool, light-green rod, and dark-green hinge glued together. The legs slide onto a red rod, which acts as an axle. Three orange washers separate the green hinges and keep them from sliding off.

To support each of two side weights, a yellow spool is glued to the end of a red rod and inserted into the side of a yellow foot—but not glued, to allow the angle to be adjusted. Each balance mass consists of two stacked steel nuts held together between two washers by a nut and bolt, for a total weight of about 50 grams. The nut assemblies are then attached to the yellow spools at the end of the balance rods with vinyl electrical tape. Those assemblies are tilted about 24° behind the legs.

Because the yellow spools used as feet have holes around their circumference, a strip of brass or steel that is 0.5 centimeter wide, about 0.013 cm thick, and held in place by electrical tape covers the area near the point where each foot touches the ground. The fully assembled walker has a mass of about 120 g.

Going down a narrow ramp with a slope of 4.5°, the walker takes a step every 0.5 second, advancing 1.3 cm per full step. Its side-to-side tilt while walking is about 4°. □