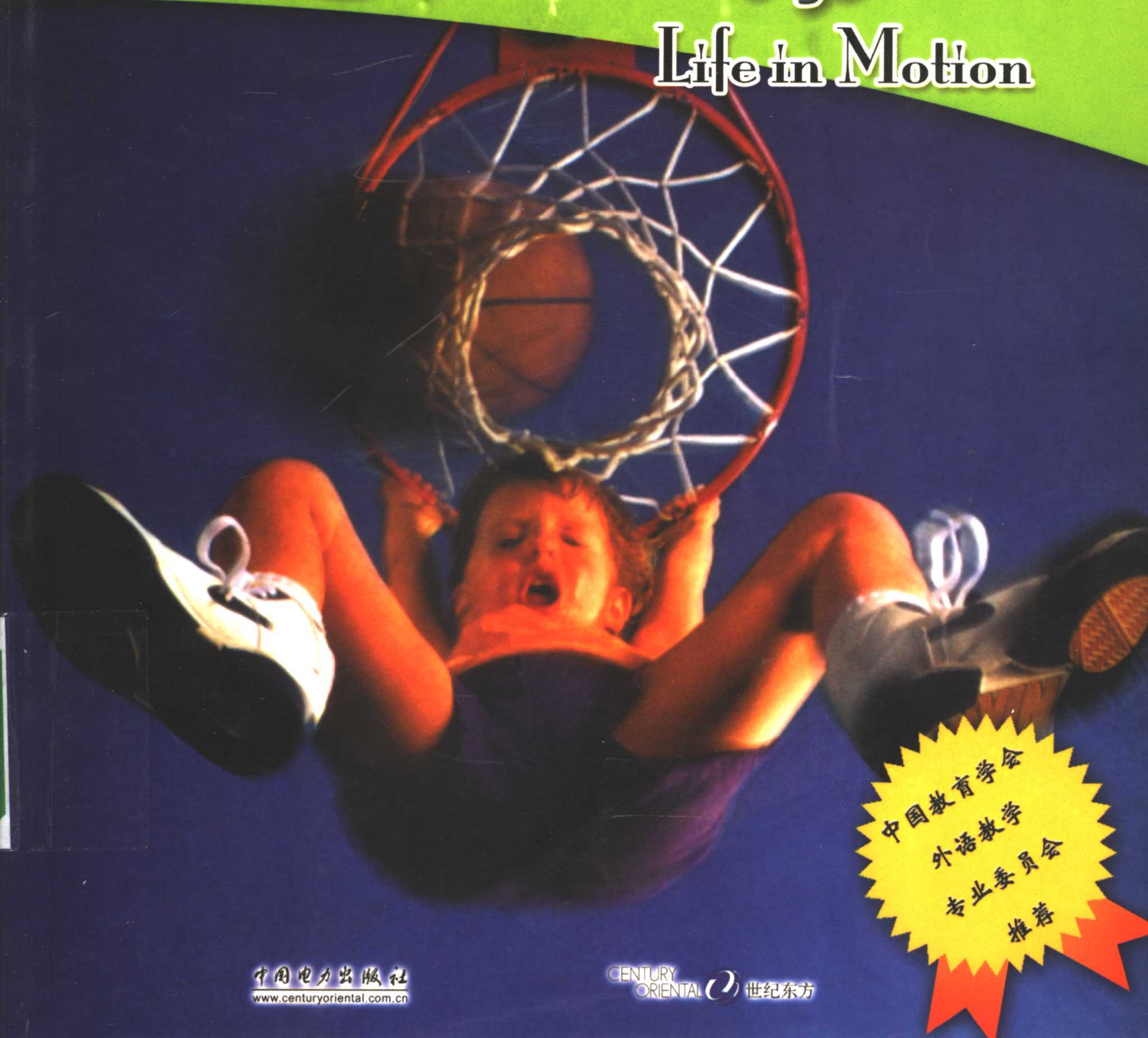
阅读空间 · 英汉双语主题阅读

高中和大学低年级适用

运动中的生命

Life in Motion



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王 新 译

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原著：**Gerald Smith** 等

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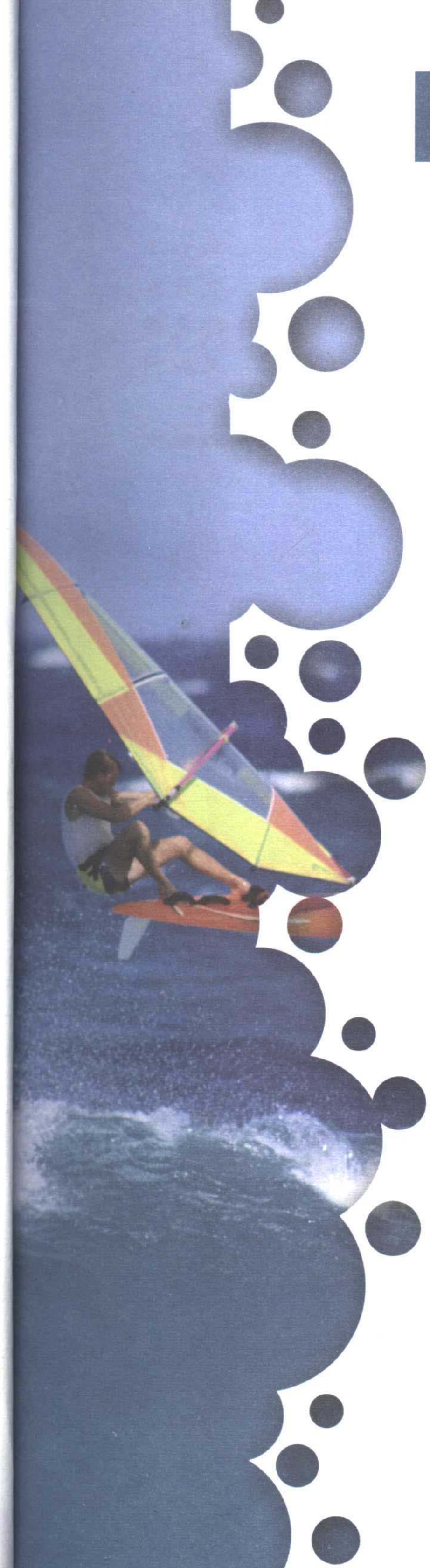

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Editor's Message 编辑手记

你是否完善了你的单排旱冰运动的模糊空翻动作或者野营时在规定时间内游过了湖面？不是很确定？别担心，还有机会。

当你阅读完本书，你对怎样能取得最佳运动表现会有一个更好的想法。生物力学——把生物学和力学相结合的科学，正帮助奥林匹克运动员创造新的纪录，教会宇航员如何在太空中行走，使科学家更加相信人体具有神奇的力学构造。

还犹豫什么？赶快开始阅读吧！

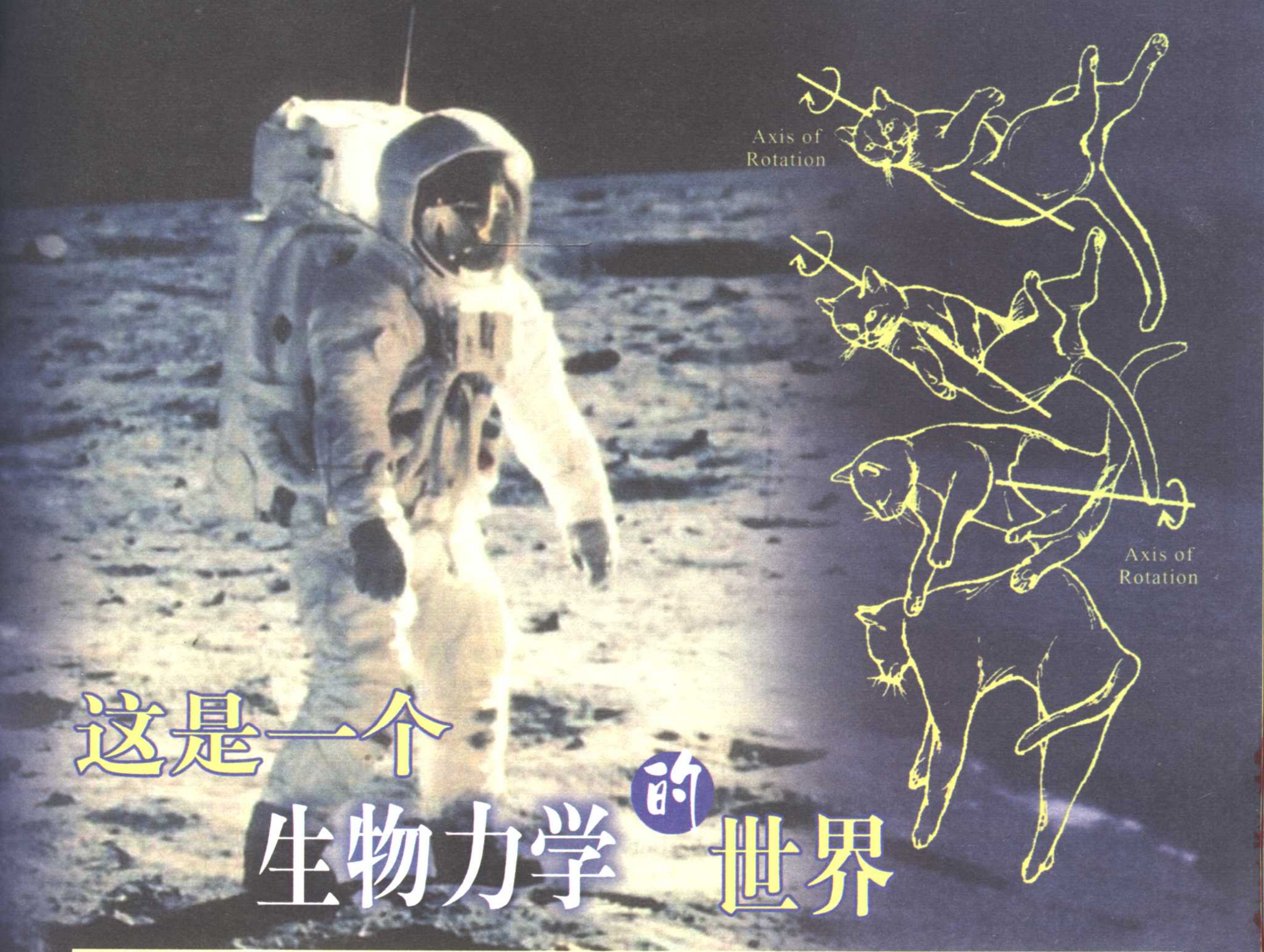
IT'S A BIOMECHANICAL WORLD!

illustration by Timothy Hengst

by Gerald Smith

More than a quarter century ago, the lunar lander Eagle touched down in the Sea of Tranquility. With the words "That's one small step for man. . .one giant leap for mankind," Neil Armstrong stepped onto the Moon's surface. Although we marvel now at the beauty of the images sent back from the Moon and think about how challenging it was to send the Apollo 11 team so far from Earth and return the astronauts safely, another pioneering accomplishment of the trip is often forgotten: The Apollo astronauts were the first humans to experience the novelty and wonder of moving about on a surface in space under greatly reduced gravity.

四分之一多世纪前，“鹰”号登月飞船在“宁静之海”着陆。伴随着“那是个人的一小步……，全人类的一大步”这句名言的出口，尼尔·阿姆斯特朗踏上了月球的表面。我们对从月球上发回的美丽照片感到惊奇，而且会想到阿波罗11号能把宇航员送到那么遥远的地方又能安全返回是多么富有挑战性。但我们却经常忘记该次航行另外一个开拓性的成就：阿波罗号上的宇航员在太空一个引力比地球引力小得多的月球表面四处走动。他们是第一批经历了这种新奇和美妙感觉的人。



这是一个生物力学的世界

How well can humans get around under such light-weight conditions? Can you walk normally? Do legs work differently on the Moon? These questions combine biology and physics and form a small part of a science that is now known as "biomechanics." This interdisciplinary field uses engineering and physics principles to study *biological* (living) systems. Early scholars such as Leonardo da Vinci (1452-1519) and Giovanni Borelli (1608-1679) were astute observers of animal and human anatomy and movement patterns. Borelli was probably the first to apply mechanical principles in an attempt to understand and explain locomotion. Today, biomechanics

在这种失重的情况下，人类四处活动的能力如何？你能正常行走吗？在月球上双腿运动的方式是否有所不同？这些问题把生物学和物理学结合到了一起。这是现在人们所称的“生物力学”这门科学中的一小部分。这门交叉学科使用工程和物理学原理研究生物（生命）系统。包括达·芬奇（1452－1519）和博雷利（1608－1679）在内的早期学者敏锐地观察到了动物和人体的解剖结构以及运动模式。博雷利大概是应用机械原理来了解并解释运动学的第一人。现在，生物力学包括众多繁杂的领域，诸如：整形术、修复术、运

includes such diverse areas as *orthopedics*, *prosthetics*, athletic performance, and even locomotion in space! Scientists with backgrounds in medicine, engineering, biology, physics, and exercise sciences share interests in understanding the mechanisms of living systems. But why study biomechanics? To better understand nature, of course – but also for more practical reasons: to treat disease, to minimize injuries, to improve athletic performance, and. . .to train astronauts for walking on the Moon.

As living and working in space someday became a clear possibility, scientists began wondering about movement under low-gravity and weightless conditions. Shortly before the Apollo missions to the Moon thirty years ago, Rudolfo Margaria, an Italian biomechanist, developed theoretical models of humans walking and running. He conjectured that under the low-gravity conditions on the Moon, where an astronaut is about one-sixth of his or her Earth weight,

Orthopedics
Branch of medicine dealing with prevention and correction of injuries to the skeletal system, muscles, joints, and ligaments

Prosthefics
Branch of medicine or surgery dealing with the production and application of artificial body parts

动表现，甚至空间运动学！在了解生命体系的机理方面，具有医学、工程、生物、物理、训练科学背景的科学家有着共同的兴趣。但是，为什么要研究生物力学？当然是为了更好地了解大自然，但也有实际原因：为了治病、减少损伤、提高运动员成绩。还有，为了训练宇航员在月球上行走。

由于将来有一天，在太空中工作和生活明显地有可能实现，科学家开始琢磨在低重力及失重条件下的运动。三十年前，在阿波罗登月之前不久，一位意大利生物力学家鲁道夫·马格拉）建立了人类行走和奔跑的理论模型。他推断，在低重力的月球上，由于宇航员的体重只有地球上体重的六分之一，为快速地在月球表面

walking and running would be less effective than hopping for quickly getting around the lunar surface. He reasoned that with reduced vertical forces, both walking and running speeds would be less than those observed on Earth because the foot would lose *traction* more easily – in effect, decreasing *propulsive* forces. The Apollo astronauts who explored outside their lunar lander found Margaria's predictions to be correct. Walking was slow and normal running didn't work well, but other unusual movements such as hopping, skipping, and loping were fast and easy in low gravity. Speaking from the Moon's surface, Gene Cernan of *Apollo* 17 said, "When I'm on level ground, I can skip. But this two-legged thing [hopping] is great! Man, I can cover ground like a kangaroo!" (See **www.odysseymagazine.com** for a NASA video clip showing an astronaut skipping and hopping on the lunar surface.)

Traction
Adhesive friction, as a foot to the ground
Propulsive
To cause to move forward or onward

Although the Apollo astronauts were the only "kangaroos" hopping across the Moon's surface, terrestrial kangaroos have long been a favorite subject of scientific study and may help to explain lunar locomotion. Kangaroos are unusual in their ability to minimize the energy required for moving. As if they had springs on each leg, they store energy "elastically" in their large tendons and muscles. This energy restores a kangaroo's forward motion with each hop. Springy legs work so well for kangaroos that it is easier for them to go fast than to go slow. Human running on Earth and hopping on the Moon may use this same technique of energy storage by momentarily stretching the tendons and muscles of the leg. (See "Springing Down the Street".)

Moon hopping in reduced gravity and floating weightless when in orbit sound like great fun, but that fun comes at some risk to astronauts' health. Very shortly after going into orbit around the Earth, dramatic physi-

移动，走和跑没有单脚跳哪么奏效。他推测说，随着垂直方向的力的下降，跑和走的速度要比地球上观测到的慢，因为脚更容易失去牵引力——实际上，也就是降低了推动力。在登月舱外探险的阿波罗号宇航员发现，马格拉的预测是正确的。行走的速度慢，正常的跑动效果不好，但是诸如单腿跳、跳跃、蹦等其他一些不寻常的运动在低重力条件下进行得既快又容易。阿波罗 17 号的吉恩·塞尔南在月球表面上这样说：“在平坦的地面上，我可以跳跃。但是这种双脚的运动（蹦）真不错！嗨，我可以像一只袋鼠一样，到处跑！”（可以登录 www.odysseymagazine.com，观看宇航局播放的宇航员在月球上跳和蹦的录像片断）。

尽管阿波罗的宇航员是在月球表面蹦蹦跳跳的惟一“袋鼠”，但是，陆地上的袋鼠一直是科学研究的首选对象，这种研究可能会帮助了解月球运动。在最大限度地降低运动所需要的能量方面，袋鼠很不寻常。它们好像每条腿上都装了弹簧，能“伸缩自如”地把能量储存在巨大的腱和肌肉里。袋鼠每向前蹦一下，这种能量就会帮它恢复体力。袋鼠具有的弹性双腿运动非常灵活。对它们来说，快跑要比慢走容易。人类在地球上跑和在月球上蹦，都可以通过暂时伸展腿上的肌肉和腱，来使用这同一种储存能量的技巧（参见《沿街跳》一文）。

在低重力的月球上跳跃，或者在进入轨道后的失重状态下飘浮，这些听起来都很有趣，但是这种有趣是以给宇航

ological changes occur within an astronaut's body – fluids shift into the trunk, and bone minerals start decreasing. These are serious matters! When astronauts return to Earth, if their bones have been weakened too much, fracturing can occur under normal-gravity weight. Even scarier, long-term *osteoporosis*, a disease in which the bones become extremely porous, may disable an astronaut in later life.

Why does weightlessness cause such changes in bone? If you have observed athletes in training over a period of time, you know how muscles can grow larger and stronger. Bone does the same thing – it adapts itself (getting stronger or weaker) according to the loads that are applied to it. This response is often called "Wolff's law," after a researcher who described bone adaptation. If large forces are applied to bone, it gets stronger. If little force is applied, it gets weaker because extra strength is unnecessary. Much of the inside of bone is hollow, with only thin *trabeculae* reinforcing the larger structure. When bone weakens, fewer trabeculae fill the hollow interior, making it susceptible to collapse or crushing.

The walking, running, and jumping that we do every day on Earth involve loads to the skeleton that are many times our body weight. (See **www.odysseymagazine.com** for a video clip showing how large the forces can be during simple jumping.) These naturally occurring forces keep our bones healthy. But weightless in space, astronauts can't easily walk or run or jump – at least without some special devices. Imagine trying to run on a treadmill. First step and wheeeeee – off you go into space! Now imagine attaching yourself to the treadmill with bungee cords or elastic straps to pull you back down for another step. The attach-

员健康可能带来的损害为代价的。进入围绕地球运行的轨道不久后，宇航员体内很快就发生了巨大的生理变化——液体进入躯干，骨骼中的矿物质开始减少。这是很严重的问题！宇航员回到地球后，如果他们的骨骼减弱了很多，在正常重力作用下，就可能出现骨折。更可怕的是，骨质疏松可能使一名宇航员的后半生变为残疾。得了这种病，骨头非常容易渗水。

为什么失重会带来骨质的这些变化呢？如果你在一段时间内观察运动员训练，你就知道肌肉如何可以变大变强。骨骼也是如此——它能自己（变强或变弱）同施加于它的负荷相适应。这一反应经常被称为“沃尔夫法则”。这一法则是以沃尔夫命名，他是一位骨骼适应性的研究人员。如果在骨骼上施加更大的力，骨骼就会变强。如果力小，骨骼就会变弱，因为这时获得多余的力量也没用。骨骼内部大部分是空的，只有薄薄的横隔片能增强较大的骨结构。骨骼弱化时，其内部的横隔片就会减少。这样就很容易发生骨骼垮塌和骨折。

我们每天在地球上走、跑、跳的时候给骨骼施加的负荷是我们体重的好几倍。（登录 www.odysseym-agazine.com 看一则录像剪辑，它说明简单跳跃可能产生多大的力）。这些自然产生的力保证我们骨骼的健康。但是在太空中失重的情况下，宇航员无法自如地走或跑或跳——至少在没有特殊设施帮助的情况下是不可能的。设想一下努力在踏

Osteoporosis
Disease in which the bones become extremely porous, are subject to fracture, and heal slowly

Trabeculae
Needlelike structures forming a supportive network in bone

ments create an artificial gravity that allows walking and running for fun, for exercise, and for bone health.

Does space biomechanics tell us anything about living on Earth? You bet! The same principles apply: For healthy bone, exercise that generates substantial forces across the skeleton is important. Sedentary lifestyles simulate an astronaut's weightlessness without the fun! So go out and run around the block – your bones will thank you someday.

While you're out running, ever wonder how athletes manage to run so fast or jump so far on Earth? That's part of biomechanics, too. In studies during recent Olympic Games, movement characteristics of runners, gymnasts, divers, swimmers, skaters, and skiers have been analyzed using three-dimensional video techniques. Multiple video cameras record a performance during competition; later, each video frame is painstakingly "digitized" to determine instantaneous body position. Full body, three-dimensional models can then be developed to assess and optimize performances (see "Smooth Riding"). Using such methods, angular momentum analysis of divers and gymnasts has shown them to use rotational strategies similar to those used by weightless astronauts and falling cats! If you have ever watched a cat turn over in mid-air, you've seen rotation while "conserving angular momentum." This is a great trick and involves applying principles of physics

车上跑。刚迈了一步，喔，你就飞了起来！现在设想一下你用橡皮筋或松紧带把自己和踏车绑在了一起。你迈每一步这些东西都会把你向下拽。这些附加物创造了一个人工的重力，使得走或跑不但有趣，还可以锻炼身体，强化骨骼。

太空生物力学是否也告诉我们一些地球上生活的知识？当然！同样的原理也适用于地球上：为了获得健康的骨骼，让骨骼承受巨大的额外压力的锻炼是重要的。经常坐着不动的生活习惯会产生类似于宇航员在失重状况下所经历到的索然无趣的感觉。因此，到外面去，围着街区跑一跑。总有一天你的骨骼会感谢你的。

你在户外跑步的时候，是否曾想过为什么运动员能在地球上跑得这么快或跳得这么远？这也是生物力学的一部分。在最近奥运会期间所作的研究中，跑步、体操、跳水、游泳、滑冰和滑雪运动员的运动特征被用三维影像技术加以分析。在比赛时，多台摄像机为一个动作录像；后来，每个画面都被艰难地进行数字化来决定运动瞬时身体的位置。然后人们就可以制作全身的三维模型来评价和优化成绩（参见

whether a cat knows them or not! But divers, gymnasts, and astronauts can be taught how to use physics to advantage. Biomechanics has also helped athletes understand why some techniques are more effective than others and has influenced equipment development such as the clap skate for speed skaters (see "To the Limit").

From astronauts skipping and hopping to athletes running, biomechanics contributes to our understanding of the motion of biological systems. Throughout this book you will encounter biomechanics in action. Look around you; from the running shoes you wear to the space shuttle you see orbiting Earth, biomechanics influences your life.

《骑得溜》一文)。使用这些方法对跳水和体操运动员进行的角动量分析表明，他们使用了和失重状态下的宇航员以及下落的猫所使用的同样的翻转技巧。如果你看到过一只猫在空中翻身的话，你就看到在"保存角动量"同时所作的旋转动作。无论猫是否了解这一点，这都是一种很高的技巧，涉及对物理学原理的应用。但是，我们可以教跳水、体操运动员和宇航员如何利用物理学。生物力学也能帮助运动员明白为什么一些技巧比另外一些更加行之有效。生物力学影响了运动器材的发展，例如速滑运动员使用的折叠冰鞋（参见《直逼极限》一文）。

从宇航员的跳与蹦，到运动员的跑，生物力学对于我们理解生物系统的运动作出了贡献。本书从始至终，你都会实际地遇到生物力学的作用。看看周围，从你穿的跑鞋，到围绕地球运行的宇宙飞船，生物力学在影响着你的生活。

Springing Down the Street

by Steve Miller

Think about the shape of your body. Don't think about whether you're tall and thin, or short and more round. Think about the real shape of the human body – most of your weight is on top, above two relatively thin legs. That's not an easy design to balance!

想一下自己的体形，不要考虑自己是又高又瘦，还是又矮又胖。想一下人类身体的真实形状——你的大部分重量在上身，而依靠两条相对较细的腿支撑。这一设计可不是很容易保持平衡的！

沿街跳

Try standing with your feet together and your hands by your side. Close your eyes and tilt your head back. Notice how much you sway back and forth. Pay attention to your body and you will feel muscles constantly tightening and releasing to keep you from toppling over. Now compare that to your dog balancing on its four legs or a beetle on its six. A lot easier for them, isn't it? That's why most walking robots look more like bugs than people (except for C3PO, but then most robots don't complain as much as him either!). And have you ever seen a spider trip and fall?

Now let's add one more complication to human locomotion – when you walk, you are on only one foot most of the time. So how do you keep upright as you walk? Well, one way to keep your balance is for your brain to send signals to your muscles telling them to contract and pull you back into position – that's why although you started to sway when you were standing

双腿收紧，双手放在身体两侧站好。闭上眼睛，头向后仰。注意自己的身体前后摆动的幅度有多大。注意一下自己的身体，你就会发现，肌肉为了防止你摔倒不停地松弛和紧张。现在，把你的动作同四条腿保持平衡的狗，以及六条腿保持平衡的甲壳虫比较一下。它们要保持身体平衡比你要容易多了，不是吗？这就是为什么大多数能行走的机器人看起来更像虫子而不像人（除了C3PO，但是当时大多数机器人也不像他那样抱怨！）。你见过蜘蛛一失足掉下来的时候吗？

现在，让我们再给人类运动加上一个复杂因素——你行走的时候，多数情况下是一只脚着地。那么，你行走时如何保持直立呢？好吧，保持平衡的一个办法是大脑向你的肌肉发送信号，告诉它们收缩，将你拽回原位——当你静止站

still, you were able to recover. Constant tiny adjustments of your muscles pulled you back up whenever you started to lean in any direction.

Now, walk slowly and really concentrate on what your body is doing – which muscles you are using when. Notice when your ankles, knees, and hips bend. There's a lot happening. But researchers in biomechanics labs are finding that you may not be using your brain to control all of these walking motions. Michael Coleman was a graduate student at Cornell University, working with Andy Ruina, a professor of theoretical and applied mechanics, when he built a two-legged machine from Tinkertoys in an attempt to figure out how human bodies work.

"It can't stand still, but it can walk without any motors to control it," Ruina says of the toy walker. "We've found that machines can do interesting things – and human bodies may operate as machines. A lot of how we move might be by design rather than control. If a construction made of pieces of plastic can walk by mechanical forces, maybe a construction of bones and tendons does the same thing," Ruina points out.

So if we move like a machine, can we design a simple model to explain the mechanics of human locomotion? Actually, humans usually use one of two completely different gaits, or ways of moving the feet and legs. You can probably guess what they are – walking and running. (There are a few others – skipping, galloping, hopping – but these are used for fun or for special instances such as moving around on the Moon. See "It's a Biomechanical World!") When you walk, you always have one foot on the ground. Biomechanists use the model of an inverted pendulum to explain how

立时开始摇晃却能够恢复原状，原因也就在此。无论你开始向哪个方向倾斜，肌肉随时的调整能够把你拉回来。

现在，慢慢地走，注意自己身体的每一个动作——什么时候你在使用哪块肌肉。注意什么时候你的脚踝、膝盖和胯部在弯曲。类似的动作有很多，但是生物力学实验室的研究人员发现，你可能并不是用大脑在控制所有的这些行走运动。迈克尔·科尔曼是康奈尔大学的一名研究生。他和理论及应用力学教授安迪·瑞纳一起，为了研究人类身体如何工作，用装配式玩具的部件制造了一台两条腿的机器。

“它不能站立不动，但是在没有引擎控制下它可以走，”瑞纳这样描述这个机器玩具。“我们发现机器可以做一些有趣的事情——人类的身体可能会像机器一样运转。我们很多运动方式是设计的结果而非控制的事情。如果一个塑料零件制成的结构能在机械力的作用下行走的话，那么，骨骼和腱组成的结构也可以完成这件事，”瑞纳指出。

因此，如果我们像机器一样运动，那我们是否可以设计一个简单的模型来

this works. As you lift one leg, the mass of your upper body moves forward in an arc, swinging over your stationary foot like an upside-down pendulum. Some of the energy of this motion carries you into the next swing over the opposite foot. Your muscles lift your mass (or weight) to a maximum height in the middle of your stride. As your body comes back down, the force of gravity adds energy to your next step. As your body swings back and forth in a pendulumlike motion over your legs, as much as 65 percent of the total energy generated by your muscles is recovered.

Running is a completely different gait than walking, and requires a different model. When you run, you don't transfer mass gently from one foot to the other. Instead, your body acts like a mass bouncing up and down on two springs – your legs. The muscles of one leg propel you into the air; then you come down on the other foot. The leg bends at the ankle and knee. Energy is stored and released, not by gravity, but by your tendons, muscles, and ligaments. Tendons and ligaments are the connective tissues that hold your bones together and connect them to muscles. They are stretchy, like a rubber band. When you are running, the force of your body hitting the ground stretches them. A large part of the energy storage is in a tendon (the Achilles) that runs around the back of your ankle, connecting your foot to the back of your leg, and a tendon in the front of your knee, which connects the upper and lower parts of your leg. As you move upward into your next stride, the stretched tissues spring back to their relaxed length, returning the stored energy to the body.

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解释人类运动的机理？实际上，人们一般从两种不同的步伐（迈步方法）中选择一种来移动腿和脚。你可以猜出来这两种方式是什么——走和跑（还有另外几种步伐——跳跃、飞奔和单腿跳，但是这些动作是为了好玩或者用于在像月球那样的地方行走的。参见《这是一个生物力学的世界》一文）。你走路的时候，总是一只脚着地。生物力学家使用一个倒转的钟摆模型来解释其原理。随着你抬起一条腿，你大半个上身呈弓形向前移动，就像一个上下倒置的钟摆一样，在静止的腿上方摆动。这一动作中的一些能量会使你的身体在另一条腿的上方摆动。在你迈步的过程中，你的肌肉会把你的质量（或重量）抬到最高点。随着身体重心回到下面，重力的作用会为你的下一步增加能量。随着你的身体围绕双腿像钟摆一样前后运动，肌肉释放出的能量的65%都得到了恢复。

跑动用的是和走截然不同的步伐，需要用另外一个模型来解释。你跑动的时候，不是缓缓地把身体从一条腿换到另外一条腿上。相反，你的身体就像在两个弹簧上上下运动。这两个弹簧就是你的两条腿。一条腿上的肌肉把你推向空中，接下来你落在另外一条腿上。腿在膝盖和脚踝处弯曲。能量被存储和释放，但靠的不是重力，而是你的腱、肌肉和韧带。腱和韧带是固定骨骼并把它们和肌肉连接起来的组织。它们就像橡皮筋一样可以拉长。当你奔跑的时候，身体落地的力量将它们拉长。大部分能量储存在脚踝后面和膝盖前面的腱里。脚踝后面的腱将脚和腿的后部连接，膝盖前面的腱则连接大腿和小腿。当你向前又迈出一步的时候，拉长的组织弹回到放松状态，将