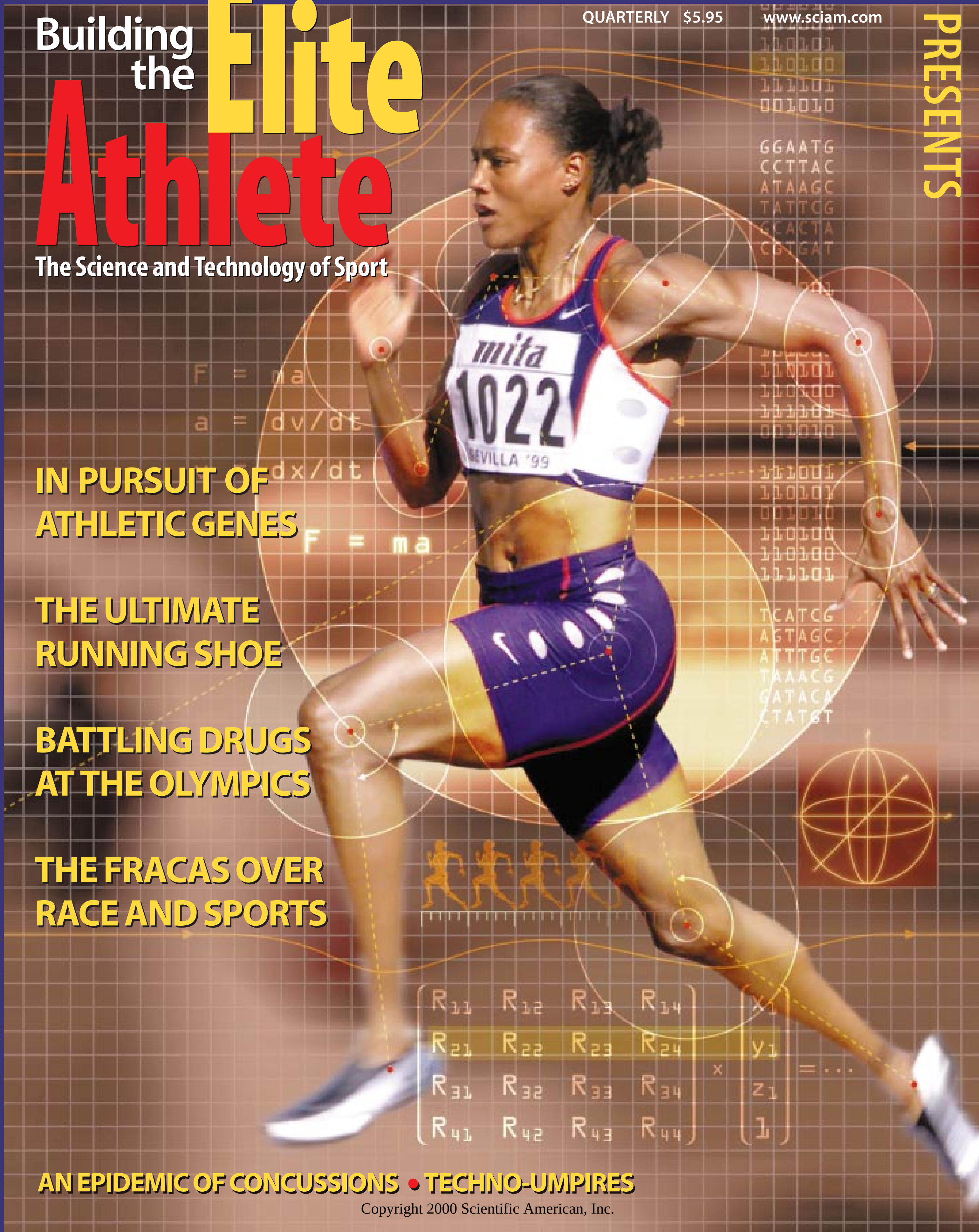
SCIENTIFIC AMERICAN PRESENTS
QUARTERLY $5.95 www.sciam.com

Building the Elite Athlete

The Science and Technology of Sport



IN PURSUIT OF ATHLETIC GENES

THE ULTIMATE RUNNING SHOE

BATTLING DRUGS AT THE OLYMPICS

THE FRACAS OVER RACE AND SPORTS

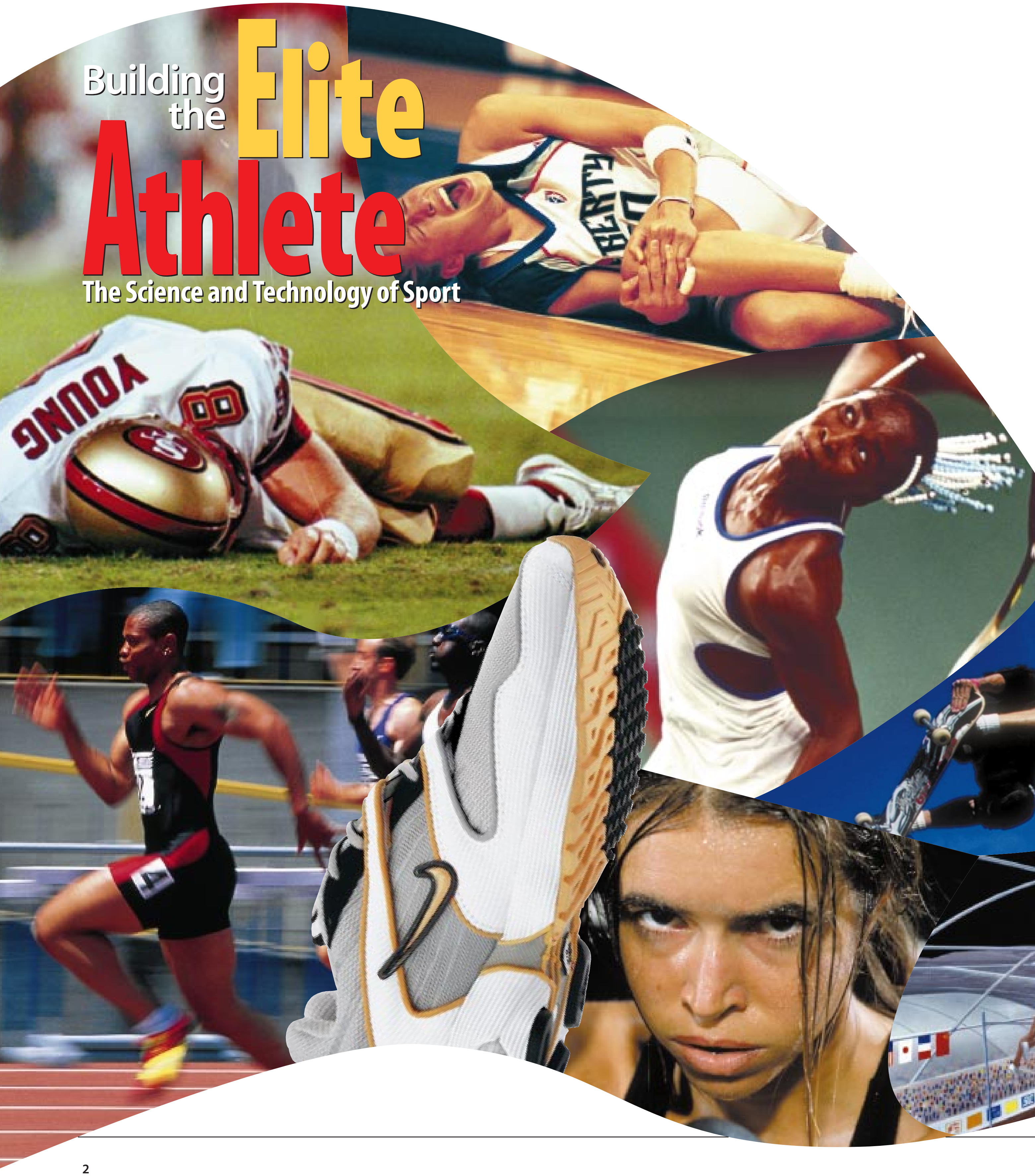
AN EPIDEMIC OF CONCUSSIONS • TECHNO-UMPIRES

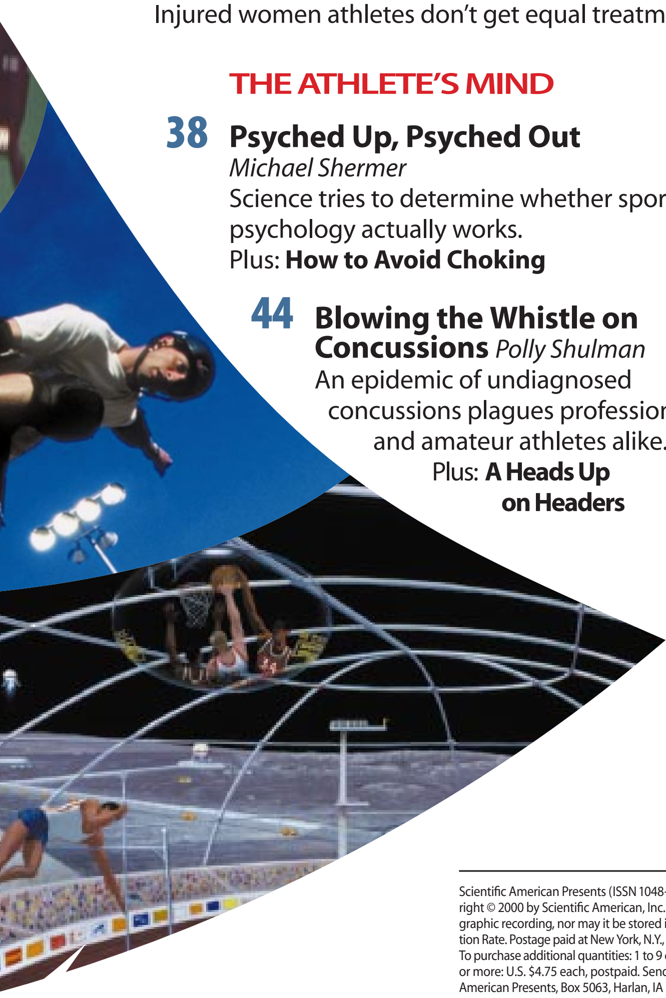
SCIENTIFIC AMERICAN PRESENTS BUILDING THE ELITE ATHLETE Quarterly Volume 11, Number 3

SCIENTIFIC AMERICAN PRESENTS
Fall 2000 Volume 11 Number 3

Building the Elite Athlete

The Science and Technology of Sport





ABOUT THE COVER
Photograph of Marion Jones by Lionel Cironneau/AP Photo. Illustration by Slim Films. Biomechanics data courtesy of Ariel Dynamics.

Scientific American Presents (ISSN 1048-0943), Volume 11, Number 3, Fall 2000, published quarterly by Scientific American, Inc., 415 Madison Avenue, New York, NY 10017-1111. Periodicals Publication Rate. Postage paid at New York, N.Y., and at additional mailing offices. Canadian BN No. 127387652RT; QST No. Q1015332537. Subscription rates: one year $19.80 (outside U.S. $23.80). To purchase additional quantities: 1 to 9 copies: U.S. $5.95 each plus $2.00 per copy for postage and handling (outside U.S. $5.00 P&H); 10 to 49 copies: U.S. $5.35 each, postpaid; 50 copies or more: U.S. $4.75 each, postpaid. Send payment to Scientific American, Dept. SAQ, 415 Madison Avenue, New York, NY 10017-1111. Postmaster: Send address changes to Scientific American Presents, Box 5063, Harlan, IA 51593. Subscription inquiries: U.S. and Canada (800) 333-1199; other (515) 247-7631.

SCIENTIFIC AMERICAN

Sandra Ourusoff
PUBLISHER
saourusoff@sciam.com

NEW YORK ADVERTISING OFFICES
415 MADISON AVENUE
NEW YORK, NY 10017
212-451-8523
fax 212-754-1138

Denise Anderman
ASSOCIATE PUBLISHER
danderman@sciam.com

DALLAS
THE GRIFFITH GROUP
972-931-9001
fax 972-931-9074
lowcpm@onramp.net

U.K. AND SCANDINAVIA
Roy Edwards
INTERNATIONAL ADVERTISING DIRECTOR
Julie Swaysland
Chester House
25 Ecclestone Place
London SW1W 9NF
England
+44 207 881-8434/35
fax +44 207 881-8503
redwards@sciam.com
jswaysland@sciam.com

FRANCE
Christine Paillet
AMECOM
115, rue St. Dominique
75007 Paris
France
+33 1 45 56 92 42
fax +33 1 45 56 93 20

GERMANY
Rupert Tonn
John Orchard
PUBLICITAS GERMANY GMBH
Oederweg 52-54
D-60318 Frankfurt am Main
Germany
+49 69 71 91 49 0
fax +49 69 71 91 49 30
rtonn@publicitas.com
jorchard@publicitas.com

MIDDLE EAST AND INDIA
PETER SMITH MEDIA & MARKETING
+44 140 484-1321
fax +44 140 484-1320

JAPAN
PACIFIC BUSINESS, INC.
+81 3-3661-6138
fax +81 3-3661-6139

KOREA
BISCOM, INC.
+82 2 739-7840
fax +82 2 732-3662

HONG KONG
HUTTON MEDIA LIMITED
+85 2 2528 9135
fax +85 2 2528 9281

Scientific American, Inc.
415 Madison Avenue
New York, NY 10017-1111
212-754-0550

OTHER EDITIONS OF SCIENTIFIC AMERICAN

Spektrum der Wissenschaft
Spektrum der Wissenschaft
Verlagsgesellschaft mbH
Vangerowstrasse 20
69115 Heidelberg, GERMANY
tel: +49-6221-50460
redaktion@spektrum.com

POUR LA SCIENCE
Pour la Science
Éditions Belin
8, rue Férou
75006 Paris, FRANCE
tel: +33-1-55-42-84-00

LE SCIENZE
Le Scienze
Piazza della Repubblica, 8
20121 Milano, ITALY
tel: +39-2-29001753
redazione@lescienze.it

INVESTIGACION CIENCIA
Investigacion y Ciencia
Prensa Científica, S.A.
Muntaner, 339 pral. 1.[a]
08021 Barcelona, SPAIN
tel: +34-93-4143344
precisa@abaforum.es

العلوم
Majallat Al-Oloom
Kuwait Foundation for
the Advancement of Sciences
P.O. Box 20856
Safat 13069, KUWAIT
tel: +965-2428186

SWIAT NAUKI
Swiat Nauki
Proszynski i Ska S.A.
ul. Garazowa 7
02-651 Warszawa, POLAND
tel: +48-022-607-76-40
swiatnauki@proszynski.com.pl

日経サイエンス
Nikkei Science, Inc.
1-9-5 Otemachi, Chiyoda-ku
Tokyo 100-8066, JAPAN
tel: +813-5255-2821

СВІТ НАУКИ
Svit Nauky
Lviv State Medical University
69 Pekarska Street
290010, Lviv, UKRAINE
tel: +380-322-755856
zavadka@meduniv.lviv.ua

ΕΛΛΗΝΙΚΗ ΕΚΔΟΣΗ
Scientific American Hellas SA
35–37 Sp. Mercouri St.
Gr 116 34 Athens GREECE
tel: +301-72-94-354
sciam@otenet.gr

科学
Ke Xue
Institute of Scientific and
Technical Information of China
P.O. Box 2104
Chongqing, Sichuan
PEOPLE'S REPUBLIC OF CHINA
tel: +86-236-3863170

SCIENTIFIC AMERICAN PRESENTS

Building the Elite Athlete is published by the staff of SCIENTIFIC AMERICAN, with project management by:

John Rennie, EDITOR IN CHIEF
Gary Stix, ISSUE EDITOR
Michelle Press, MANAGING EDITOR
Marguerite Holloway, Steve Mirsky, CONTRIBUTING EDITORS
Glenn Zorpette, STAFF WRITER

Contributors
John B. De Santis, DESIGN DIRECTOR
Mark Fischetti, ISSUE EDITOR
Lisa Burnett, PRODUCTION EDITOR
Naomi Beth Lubick, Eugene Raikhel, RESEARCHERS

Art
Johnny Johnson, ART DIRECTOR
Bridget Gerety, PHOTOGRAPHY EDITOR

Copy
Maria-Christina Keller, COPY DIRECTOR
Molly K. Frances, COPY CHIEF
Daniel C. Schlenoff; Myles McDonnell; Rina Bander; Sherri Liberman

Administration
Rob Gaines, EDITORIAL ADMINISTRATOR
Eli Balough

Production
William Sherman, ASSOCIATE PUBLISHER, PRODUCTION
Janet Cermak, MANUFACTURING MANAGER
Carl Cherebin, ADVERTISING PRODUCTION MANAGER
Silvia Di Placido, PREPRESS AND QUALITY MANAGER
Georgina Franco, PRINT PRODUCTION MANAGER
Christina Hippeli, PRODUCTION MANAGER
Norma Jones, ASSISTANT PROJECT MANAGER
Madelyn Keyes, CUSTOM PUBLISHING MANAGER

Circulation
Lorraine Leib Terlecki, ASSOCIATE PUBLISHER/ VICE PRESIDENT, CIRCULATION
Katherine Robold, CIRCULATION MANAGER
Joanne Guralnick, CIRCULATION PROMOTION MANAGER
Rosa Davis, FULFILLMENT AND DISTRIBUTION MANAGER

Marketing
Laura Salant, ASSOCIATE PUBLISHER, STRATEGIC PLANNING

Subscription Inquiries
U.S. and Canada 800-333-1199;
Other 515-247-7631

Business Administration
Christian Kaiser, DIRECTOR, FINANCIAL PLANNING
Marie Maher, BUSINESS MANAGER
Constance Holmes, MANAGER, ADVERTISING ACCOUNTING AND COORDINATION

Electronic Publishing
Martin O. K. Paul, DIRECTOR

Ancillary Products
Diane McGarvey, DIRECTOR

Chairman Emeritus
John J. Hanley

Chairman
Rolf Grisebach

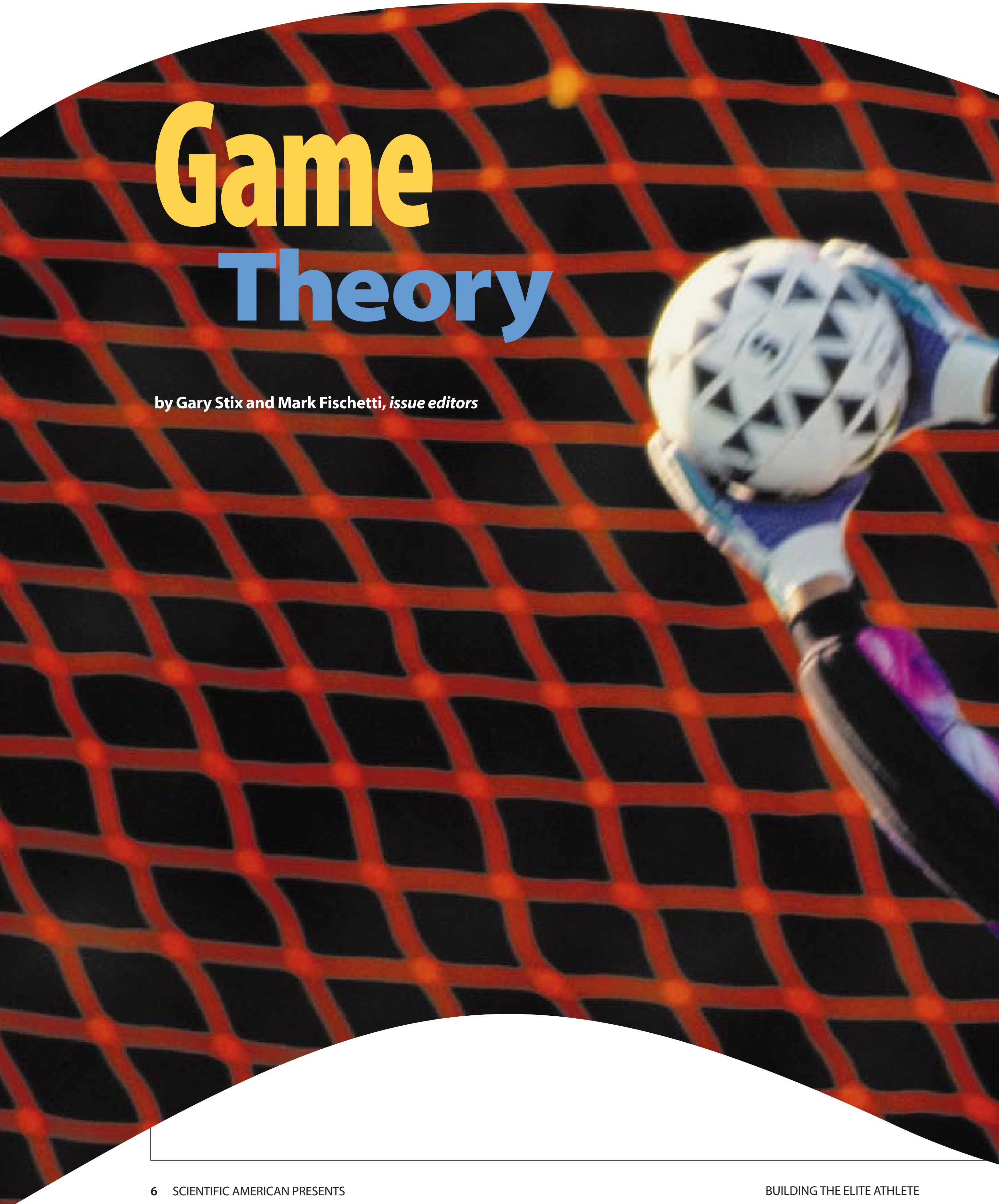
President and Chief Executive Officer
Gretchen G. Teichgraeber

Vice President and Managing Director, International
Charles McCullagh

Vice President
Frances Newburg

Game Theory

by Gary Stix and Mark Fischetti, *issue editors*



At the ancient Olympics, the Greeks practiced the long jump. But no one really knew how long anyone jumped. Exact distance was a sketchy notion. As sports historian Allen Guttmann notes, a unit of length in Sparta differed from one in Athens. Comparison of performances from one competition to the next was impossible and bore no interest anyway to the sponsors of what were mostly religious and ritualistic events.

It wasn't until a few millennia later that modern sport made its debut, characterized by precise quantification of distance and time. The machine age began an era of standardization in sport, which prompted rules and regulations, timepieces, set-length playing fields, scoring systems and sophisticated equipment.

This rationalism was gradually applied to improving an athlete's body and skill. Physical conditioning has ancient roots in the Greek and Roman desire to develop superior soldiery. But a rigorously scientific approach to *citius, altius, fortius*—the Olympic motto of swifter, higher, stronger—came only in the 20th century.

Today the burgeoning base of scientific and technical knowledge in industrial countries has channeled enormous effort into transforming sport into science that goes beyond traditional trial-and-error methodology. To provide the elite athlete with that critical edge, scientists and technologists are now trying to de-

R. W. JONES *Corbis*

DAVID MADISON *Tony Stone Images*

fine athletic performance as a set of physical parameters (force vectors and acceleration), biological processes (pulse rate and maximum oxygen uptake) and mental states (psyched up or psyched out).

Physiologists, kinesiologists, nutritionists, biomechanists and psychologists (and sometimes even coaches) have put their thoughts to formulating questions about how to translate fundamental insights from physics and biology into practical training technique. Is there a "perfect" swimming stroke that can create the hundredths-of-a-second advantage that distinguishes a winner from an also-swam? Can skateboarders, snowboarders, gymnasts and divers perform even more complex maneuvers with a better understanding of how to exploit the physics of twisting bodies?

Inquiries into physiology can sometimes spill over into sociology: Do black athletes have an inborn advantage over whites? And why is it that certain poor, tiny countries are able to produce the dominant players in particular international sports?

Engineering better equipment can aid athletes as well—sometimes too much. Advances in golf balls, javelins, speed skates and tennis rackets have so improved performance that occasionally they have had to be regulated or banned so as not to undermine the fundamental human challenge that defines a game.

Technology has also helped spawn the phenomenon of extreme sports: rebreathers used by cave divers, which recycle their own breathing gases, let them remain submerged in black, water-filled passages deep in the earth for more than 12 hours.

The importance that society accords to ensuring the health and welfare of a linebacker or point guard has fostered a concurrent boom in sports medicine. Clearer understanding of how an individual responds to being elbowed repeatedly in the head during the course of a hockey season has led to a startling lesson about the physiology underlying concussions—even a series of seemingly minor blows can cause permanent damage to the brain. And the widespread participation of women in sports has prompted a long-overdue focus on the special types of injuries they experience.

Sports scientists may have finally reached a point where they have bragging rights. New insights into fast-twitch muscle fiber and VO_2max, combined with the introduction of better gear, may help explain why almost every athletic record in the books continues to be broken. And this unceasing one-upmanship highlights a more profound scientific debate over whether we have begun to approach the limits of human performance in running, jumping and lifting.

All this achievement, though, masks a stark reality. So far we have attained only an imperfect realization of sport as science. Logically, the search for the ultimate athlete would culminate in combing through human DNA for genes that can distinguish between the future Olympian and someone who

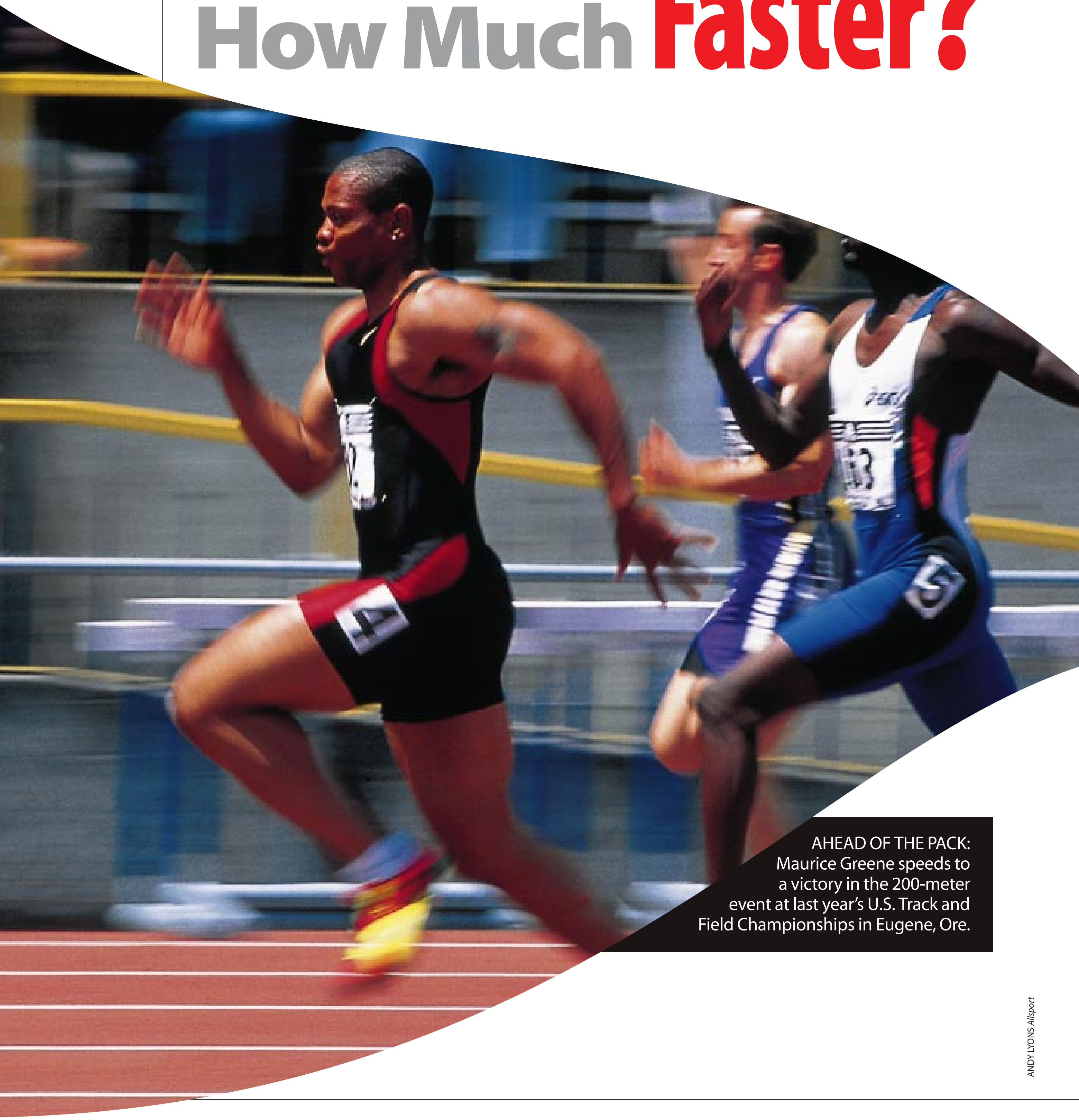
DAVID MADISON *Tony Stone Images*

will have a tough time making high school junior varsity. Genetic investigators have found a few tantalizing clues but mostly dead ends for what could pass as "performance genes." Coaches, too, are often at odds with a science that in some cases replaces one theory with another every few years. Does the Bernoulli effect or Newton's third law explain a swimmer's propulsion? Does it matter? And sports psychology, which is supposed to keep the athlete locked into the mental game, may be less a system for training the mind than a sophisticated pep talk clothed in jargon.

The notion of the engineered athlete has also suffered because some citadels of sports science have turned out to be Potemkin villages. Confessions and court inquisitions have shown that the Soviet and East German sports institutes—which trumpeted themselves as bellwethers of systematic, dispassionate training—guaranteed success by serving as major dispensaries for anabolic steroids.

Still, sports science will have its contribution to make. As records keep falling and competition intensifies, it will become ever more difficult for an athlete to shave off that extra hundredth of a second or to squeeze another millimeter of clearance over the bar in the unceasing quest to win a ticket to the top step on the winner's podium at the next Olympics. Any leverage an athlete or coach can wrest from the wisdom of a Newton or from the engineering wizardry of a Nike will be welcomed.

How Much Higher? How Much Faster?



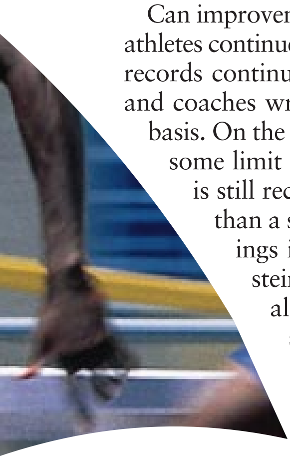
AHEAD OF THE PACK: Maurice Greene speeds to a victory in the 200-meter event at last year's U.S. Track and Field Championships in Eugene, Ore.

ANDY LYONS *Allsport*

Limits to human performance are not yet in sight

by Bruce Schechter

Last year, during a rare stationary moment, runner Maurice Greene paused to reflect on world records. "You don't try to break them," he told a reporter. "You prepare the best you can, and they will come." A few weeks later in Athens, Greene's faith and preparation were rewarded when he set a new world record for the 100-meter dash, completing 45 precise and powerful strides in exactly 9.79 seconds. Greene had bested the previous record by five hundredths of a second—an eye blink, but also the single largest reduction in the past 30 years in this event, the ultimate sprint in track and field.



Can improvements in this and other sports go on? If athletes continue to refine their preparation, will world records continue to be the reward? Sports scientists and coaches wrestle with these questions on a daily basis. On the one hand, it is clear that there must be some limit to human performance: nobody who is still recognizably human will ever run faster than a speeding locomotive or leap tall buildings in a single bound. But so far no Einstein of the athletic universe has come along to set down the limits, although some have tried.

Ever since the early years of the 20th century, when the International Amateur Athletic Federation began keeping records, there has been a steady improvement in how fast athletes run, how high they jump and how far they are able to hurl massive objects of every description, themselves included, through space. For the so-called power events—those that, like the 100-meter sprint and the long jump, require a relatively brief, explosive release of energy—the times and distances have improved about 10 to 20 percent. In the endurance events the results have been even more dramatic. At the 1908 Olympics in London, John Hayes of the U.S. team ran a marathon in a time of 2:55:18. Last year Morocco's Khalid Khannouchi set a new world record of 2:05:42, almost 30 percent faster.

No one theory can explain such improvements in performance, but perhaps the most important factor has been genetics. "The athlete must choose his parents very carefully," says Jesus Dapena, a sports scientist at Indiana University, invoking an oft-cited adage. Over the past century the composition of the human gene pool has not changed appreciably; evolution operates on a far longer timescale. But with the increasing global participation in athletics—and ever greater rewards to tempt athletes—it is more likely that individuals possessing the unique complement of genes for athletic performance can be identified early. "Was there someone like [sprinter] Michael Johnson in the 1920s?" Dapena asks. "I'm sure there was, but he was probably a carpenter in the mountains."

RUNNING ON GENETICS

Identifying genetically talented individuals is only the first step in creating world-class athletes. Michael Yessis, an emeritus professor of sports science at California State University at Fullerton, president of Sports Training in Escondido, Calif., as well as a consultant to many Olympic and professional teams, maintains that "genetics only determines about one third of an athlete's capabilities. But with the right training we can go much further with that one third than we've been going." Yessis believes that U.S. runners, despite their impressive achievements, are "running on their genetics." By applying more scientific methods, "they're going to go much faster." These methods include strength training that duplicates what they are doing in their running events as well as plyometrics, a technique pioneered in the former Soviet Union.

Whereas most exercises are designed to build up an athlete's strength or endurance, plyometrics focuses on increasing an athlete's power—that is, the rate at which she can expend energy. When a sprinter runs, Yessis explains, her foot stays in contact with the ground for only a little under a tenth of a second, half of which is devoted to landing and the other half to pushing off. Plyometric exercises help athletes make the best use of this brief interval.

Nutrition is another area that sports trainers have failed to address adequately. "Many athletes are not getting the best nutrition, even through supplements," Yessis insists. Each activity has its own particular nutritional needs. Few coaches, for instance, understand how deficiencies in trace minerals can lead to hamstring injuries.

Focused training will also play a role in enabling records to be broken. "If we would apply the Russian methods of training to some of the outstanding runners we have in this country," Yessis asserts, "they would be breaking records left and right." He will not predict by how much, however: "Exactly what the

LIFTING FOR SPEED: Olympic runner Ato Boldon takes advantage of training insights about the importance of upper-body strength for runners.

AL BELLO *Allsport*

limits are it's hard to say. They're not going to be humongous, but there will be increases even if only by hundredths of a second. They will continue, as long as our methods continue to improve."

One of the most important new methodologies to be applied to sports training over the past several decades is known as biomechanics, the study of the body in motion. A biomechanic films an athlete in action and then digitizes her performance, recording the motion of every joint and limb in three dimensions. By applying Newton's laws to these motions, a biomechanic can determine what the athlete is doing to help her performance and what is holding her back. "We can say that this athlete's run is not fast enough; this one is not using his arms strongly enough during takeoff," says Dapena, who uses these methods to help high jumpers. Generally, the changes that a biomechanic can make in athletic performance are small. "We can't dismantle an athlete's technique," he notes. "We are just putting the icing on the cake."

To date, biomechanics has helped athletes only to fine-tune their techniques. Revolutionary ideas still come from the athletes themselves. "Normally athletes, by trial and error, come up with some crazy thing," Dapena explains. For example, during the 1968 Olympics in Mexico City, a relatively unknown high jumper named Dick Fosbury won the gold by going over the bar backward, in complete contradiction of all the received high-jumping wisdom, a move instantly dubbed the Fosbury flop.

The story of Fosbury's discovery illustrates the role of serendipity in advancing biomechanics. When Fosbury was growing up in Portland, Ore., he learned to jump over the high bar using the scissors kick—hopping over the bar with his rear end down—that was taught to children. In high school, his coach tried to convert him to the "correct" international style, which involved straddling the bar face down, in a forward roll. Fosbury, a gangly adolescent, found the technique difficult to master, so his coach allowed him to use the childish scissors in one meet. His first jump was an unimpressive 5 feet 4 inches. The problem, as he saw it, was that his rear kept knocking the bar. So he modified his approach to what he called "kind of a lazy scissors." As the bar moved higher, Fosbury found that he was beginning to go over flat on his back. "I'm upside down from everybody else," he recalled. "I go over at six feet, and nobody knows what the heck I'm doing."

CLEARING THE HIGHER BAR

Fosbury himself did not know what he was doing. That understanding took the later analysis of biomechanics specialists who put their minds to comprehending something that was too complex and unorthodox to have ever been invented through their own mathematical simulations. Even before Fosbury's strange jump, scientists had long known that when a high jumper leaps, his center of mass—the point at which the mass of a body appears to be concentrated—rises to a height determined by the energy generated by his muscles. Most of the time, when standing, sitting or running, our centers of mass are more or less within our bodies, so if we want our bodies to clear a bar, our center of mass must clear the bar as well.

Fosbury accidentally discovered that this is not always true: when the human body is arched backward, the center of mass can be made to move to just outside the back. In this position, a jumper's body can clear the bar while his center of mass travels beneath it. Thus, for the same energy expenditure, an athlete doing the Fosbury flop can clear a higher bar.

The inspiration provided by Fosbury also required another element that lies behind many improvements in athletic performance: an innovation in athletic equipment. In Fosbury's case, it was an improvement in the cushions that jumpers land on. Traditionally, high jumpers would land in pits filled with sawdust; flopping over the bar and landing backward in the pit would have been a recipe for injury. But by the time Fosbury was in high school, sawdust pits had been supplanted by large, soft foam cushions, ideal for flopping.

Other sports have benefited from better equipment. Speed skating was recently revolutionized when the Dutch introduced the "clap skate," a skate with a hinge that keeps the blade on the ice longer, providing more speed. Skaters were slow to adopt this innovation, but when they did, the results revolutionized the sport, shaving seconds off previous records.

Clap skates are not the only innovation: pole vaulters have taken advantage of springier, fiberglass poles. To a lesser extent, runners have been helped by better shoes and special elastic tracks that do not absorb as much energy as previous surfaces did. The springy surface returns energy to a runner's stride that would otherwise be consumed by an ordinary track. Still, the improvements possible through these technologies are not as critical as basic athletic ability. Dapena puts the importance of equipment in perspective when he says, "If you ask, 'Would you like to have Michael Johnson's body or his shoes?' I'll take the body."

But materials do make a big difference. Gideon B. Ariel, one of the fathers of biomechanics and the founder of the Olympic Training Center in Colorado Springs, compared the performance of Jesse Owens with that of Carl Lewis. In 1936 Owens ran the 100-meter event in 10.2 seconds, much slower than the 9.86 Lewis achieved in 1991. "Of course, what Jesse Owens was running on was not the same surface that Carl Lewis ran on," Ariel explains. Owens ran on a clay track that absorbed more energy than the modern tracks on which Lewis set his record. "Imagine you're running on the beach in very deep sand. Your joints might be very fast, but you don't make the progress. If you run the same on the road, you will be faster. You're really not faster, you are more efficient—you don't lose as much energy." Ariel was able to analyze films of Owens running and determine that his joints were moving as fast as Lewis's. He determined that had Owens and Lewis run on the same track the results would not have been nearly as lopsided, although Lewis would probably still have run faster.

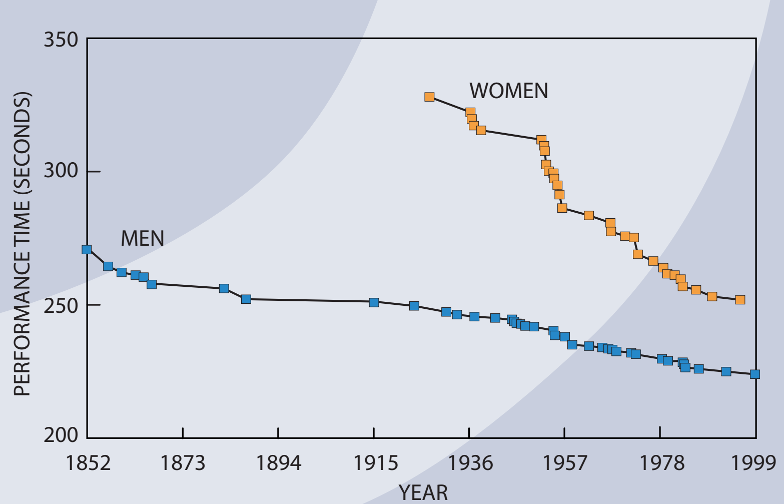
PUSHING THE LIMITS

Given the best training and the best equipment, how fast can a Michael Johnson, Maurice Greene or another genetically gifted athlete hope to run? Ariel addressed this question in 1976. He concentrated on power sports such as sprinting and jumping, because, he reasoned, these are most easily analyzed using the tools of Newtonian mechanics. "In the power events, you have anatomical restrictions like the strength of the bones and the strength of the muscles. At some point, at a certain level of force, the human body will not be able to sustain it, and a bone will crack or a tendon will come off," Ariel says. "We use data from various research institutions that show the strength of bones, the strength of connective tissues and stuff like that." To be on the safe side, Ariel decided to increase these estimates by 20 percent and then calculated the breaking point. "It is straightforward mathematics to do this calculation," he says. "I think we are pretty accurate, and the proof is that since 1976 nobody has done better than we predicted, because the human body didn't change." Specifically, Ariel predicted that no one would ever run 100 meters in less than 9.6 seconds, jump higher than 8 feet 5 inches or throw a shot farther than 75 feet 10.25 inches, and so far no person has succeeded in beating those estimates.

The limits in endurance events, which depend more on physiology than mechanics, are far harder to calculate. The reason is that to figure physiological limits requires a deep understanding of metabolism at a cellular level, something that cannot be captured by a video camera. "I'm not sure we are close to the limit," Ariel says. "Somebody might come who will run a sub-four-minute mile for 10 miles, and that would break a world record by an unbelievable amount. If you can do it for one mile, maybe you can build a training routine where you can do it for two, three or four miles."

NOT OVER YET: DECLINES IN TIMES CONTINUE FOR THE MILE

[redacted]



In the end, most people who have attempted to examine human performance are eventually humbled by the resourcefulness of athletes and the powers of the human body. "Once you study athletics, you learn that it's a vexingly complex issue," says John S. Raglin, a sports psychologist at Indiana University. "Core performance is not a simple or mundane thing of higher, faster, longer. So many variables enter into the equation, and our understanding in many cases is very, very fundamental. We've got a long way to go." For the foreseeable future, records will still be made to be broken.

BRUCE SCHECHTER is a freelancer based in Brooklyn, N.Y., and the author of *My Brain Is Open: The Mathematical Journeys of Paul Erdös* (Touchstone Books, 2000).

FURTHER INFORMATION

ATHLETICS 2000. Edited by Peter Matthews. SportsBooks, Worcester, England, 2000.

JENNIFER JOHANSEN; SOURCE: ROB WHITTINGHAM *Association of Track and Field Statisticians*

a matter of size

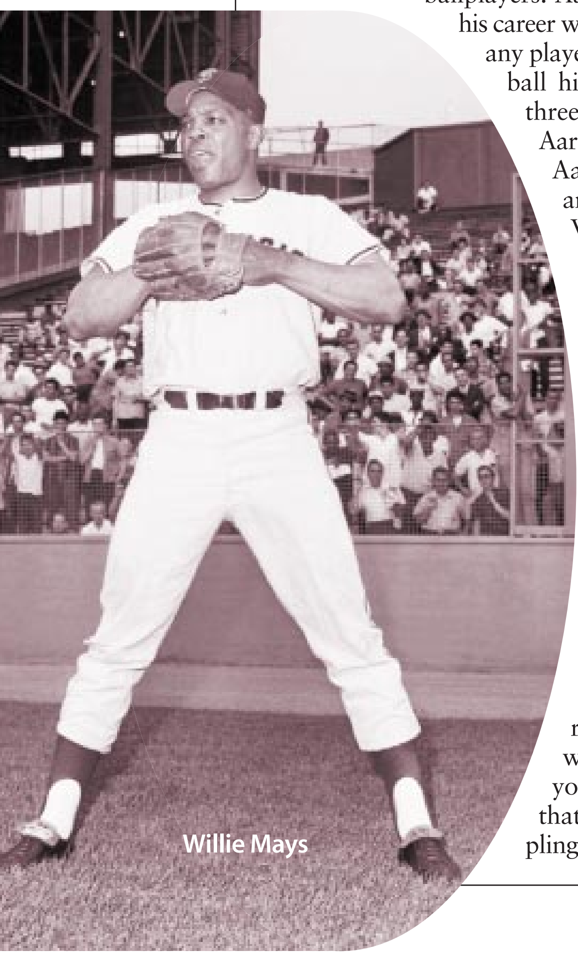
Professional players keep getting bigger, and records continue to topple

by Rob Neyer

Track and field athletes aren't the only ones who continually push the physical limits of their sports. Although some curmudgeons might still try to argue that athletes in baseball and football aren't better than their forebears, it's pointless to suggest that they're not more physically gifted. Today's competitors aren't only bigger than ever, they're stronger and faster—and this development goes a long way toward accounting for the surge in record breaking in these games.

In the 1960s the best players in baseball were arguably Hank Aaron and Willie Mays, and in fact those two are now generally regarded as the greatest living ballplayers. Aaron, of course, finished his career with more home runs than any player in Major League Baseball history; Mays is number three on the list, behind only Aaron and Babe Ruth. Hank Aaron stood six feet tall and weighed 180 pounds. Willie Mays measured 5′11″ and also weighed a modest 180 pounds.

Now, fast-forward to the 1998 season, when Mark McGwire and Sammy Sosa hit 70 and 66 home runs, respectively, and became the most famous baseball players on the planet. At 6′5″ and 250-plus pounds, McGwire resembles a refugee from the World's Strongest Man competitions. Sosa, like Aaron, reaches six feet. But he weighs 220 pounds, and if you've seen him you know that it's 220 pounds of rippling muscles.



Willie Mays

BETTMANN/CORBIS

These are, of course, isolated examples. The increase in the size of baseball players, though, has been steady and, of late, dramatic. In the 1900s the average baseball player weighed 174 pounds, compared with 186 pounds in the 1970s, an increase of 6.9 percent over that period. In the 1990s the average player weighed 198 pounds, a jump in size of another 6.5 percent in just two decades.

Clearly, these aren't your father's ballplayers. The incredible strength of today's players has contributed to a surge in scoring that might still have a ways to go. In the 1970s the average National League game saw 8.27 runs scored. In the 1980s that figure dropped ever so slightly (1.3 percent), to 8.16 runs per game. But in the 1990s National Leaguers scored 8.96 runs per game, a whopping 9.8 percent increase over the previous decade. This year a typical National League game has seen 10.6 runs, and the scoring boom shows no sign of abating. We can identify any number of factors that might be contributing to baseball's offense explosion. Smaller ballparks and the Incredible Shrinking Strike Zone are two of the more popular candidates. But watch a game on ESPN, then watch a pre-1990 game on ESPN Classic, and you'll be struck with the exterior physiological differences between the players then and the players now.

ENTER THE BASH BROTHERS

Unlike football, for many years baseball was not considered a strength sport. In fact, through most of the game's history, baseball players were generally discouraged from lifting weights, as the common wisdom held that they would become muscle-bound and lack the needed flexibility to bat and field. It wasn't until the late 1980s that everyone realized just how far pumping iron might take a team's performance. That was when Dave McKay, then the first-base coach for the Oakland Athletics and now Mark McGwire's batting-practice pitcher and first-base coach of the St. Louis Cardinals, took on the role of strength trainer for the A's at a time when nobody else had one. This move helped to propel the careers of the "Bash Brothers," hulking sluggers McGwire and Jose Canseco, as well as of smaller players such as Rickey Henderson and Walt Weiss, who were also avid workout fanatics.

In 1989 the A's beat the San Francisco Giants in the World Series, the second of three straight Series appearances for Oakland. "Other teams saw the value of weights and strength training when they saw those A's clubs, and suddenly all of them started hiring their own strength-and-conditioning coaches," remembers Billy Beane, now the general manager of the A's, who was finishing his playing career with the team at the time this bulked-up crowd emerged.

Weight training is just one "artificial" enhancement, along with specialized diets and the use of anabolic steroids. What's more, any disincentives to increase strength are falling by the wayside. Although putting on muscle may, in some instances, diminish a baseball player's speed and agility, those attributes have become less important with the construction of new, smaller, hitter-friendly baseball stadiums, where pure strength has become perhaps the most important quality in a batter. Unfortunately for the balance of power in baseball, the embrace of strength training largely excludes a team's pitching staff. "You can only build up so much strength without compromising flexibility, so there is definitely a finite limit," says Lewis A. Yocum, team physician for the Anaheim Angels. "You're simply not going to see the geometric progression you see with the pitchers as you see with the hitters."

The result, as we have witnessed lately, is prodigious power hitting, with home-run records falling all the time as batters are increasingly "selected" for their ability to hit a baseball with authority. Although various home-run records fall with apparently programmed regularity, no hitter has seriously threatened to compile a .400 batting average in recent years. What would happen, though, if a supremely talented hitter like McGwire concentrated on batting average rather than power—aiming for hits instead of home runs? We'll probably never know. As Atlanta Braves pitcher Greg Maddux put it so eloquently in a Nike commercial last year, "Chicks dig the long ball."

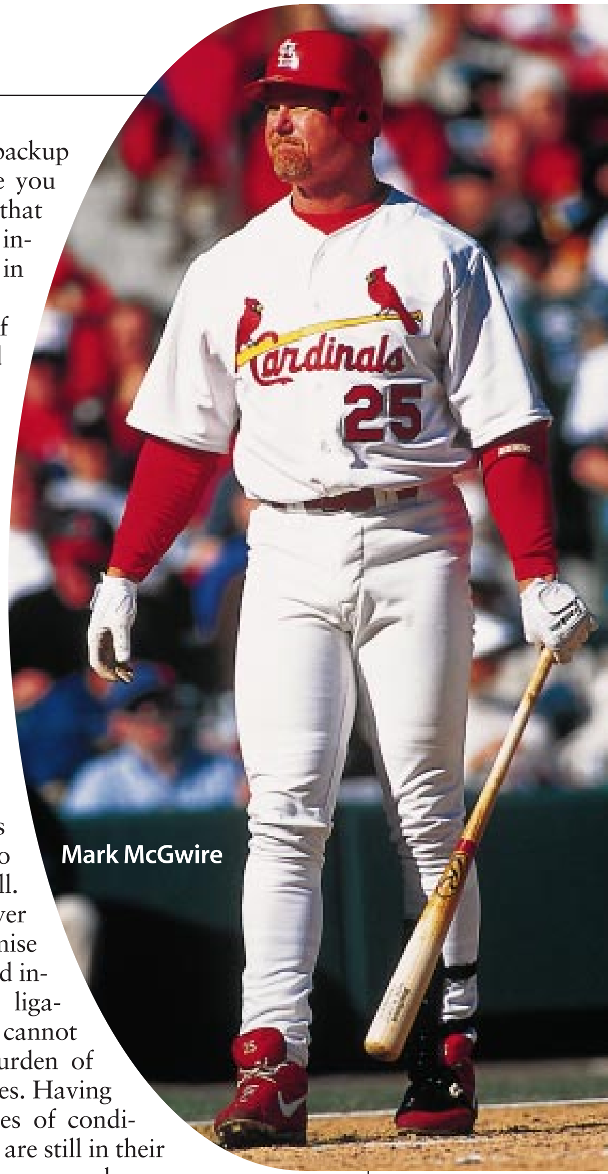
HOW BIG A LINEBACKER?

Size matters in football, too. Last year the St. Louis Rams blew away most competition on their way to a victory in Super Bowl XXXIV with an offensive line that averaged 6′5″ and 306 pounds. That compares with an average of 6′3″ and 246 pounds for the 1967 Green Bay Packers, considered the best team of its decade. Football also has its equivalent of baseball's balance of power. Whereas defensive linemen and linebackers are selected, in part, on the basis of their size and strength, quarterbacks are chosen mostly for their intelligence and their ability to throw the football. The result, many pundits suggest, is an ever-increasing injury rate encountered by quarterbacks. These days in the National Football League, it's considered crucial to have an experienced backup quarterback, because you can almost predict that your starter will be injured at some point in the season.

Where will all of this end? When asked that question, Dallas Cowboys strength-and-conditioning coach Joe Juraszek replies, "I have no idea where it's going to stop. I guess there must be a limit to all of it. But in my lifetime? I'm not sure I'll see it."

Some upper barriers must exist. It's unlikely that we'll ever see a linebacker weighing 450 pounds or a shortstop who looms seven feet tall. At some point, a player starts to compromise speed and agility—and injuries mount when ligaments and tendons cannot accommodate the burden of overdeveloped muscles. Having said that, the sciences of conditioning and nutrition are still in their relative infancies, so one can only assume that today's giant professionals will continue to develop in the three dimensions of size, strength and speed.

But this phenomenon isn't new. In his book *In the Pocket,* former NFL quarterback Earl Morrall wrote, "I think a primary reason for the increased number of knee injuries is the fact that players are bigger and faster than ever before. It's a case of a larger mass traveling at a greater speed. When they hit, they hit hard and something has to give." That was in 1969. Now we're entering the 21st century, and wouldn't you know it, here we are talking about how big and strong and fast professional athletes are.



Mark McGwire

ELSA/ALLSPORT

ROB NEYER is a senior writer with ESPN.com and recently co-authored *Baseball Dynasties,* published by W. W. Norton.

FURTHER INFORMATION

Major League Baseball's Web site (www.majorleaguebaseball.com) includes an extensive database of player statistics.

The Chemical Games

ANGUISHED CYCLIST: A member of the Banesto team tries to hide from the press after his group withdrew from the 1998 Tour de France amid a sprawling scandal linked to the drug erythropoietin.

LAURENT REBOURS *AP Photo*

by Glenn Zorpette, *staff writer*

At this year's Olympic Games, a decades-old tradition will play out between the lighting of the torch and the closing ceremonies. This will be the testing of the urine, in which scientists armed with millions of dollars' worth of state-of-the-art instruments will look for obscure molecules in incredibly small concentrations signaling the recent use of one or more banned performance-enhancing drugs.

Unless a superstar athlete is caught cheating, not many spectators will give more than a passing thought to this behind-the-scenes struggle. But as surely as athletes will pit themselves against one another, some will also match wits with doctors, technicians and sports officials. A few athletes will probably be caught, triggering an appeal and arbitration process that will unfold well away from the public eye and under the aegis of officials with little or no formal education in physiology, pharmacology, or indeed any branch of science or medicine.

Even more dispiriting, it is a virtual certainty that a larger number of cheating athletes will beat the tests. Many of them will use a drug that cannot now be detected in urine. Others will carefully schedule and limit their use of banned substances so that their biochemical indicators will be below the thresholds that the International Olympic Committee (IOC) interprets

Biotechnical advances and administrative loopholes enable devious athletes to take performance-enhancing drugs without much risk of being caught or sanctioned

as a damning result. If the previous Olympics are a guide, some athletes will even take drugs, be caught and then have their sanctions overturned by an arbitration process that tends to exonerate all but the most poorly informed and reckless cheaters.

Given the variety of ways to circumvent drug tests, officials are at a loss to say even how widely abused some of the substances are. But scattered evidence suggests troubling pervasiveness, at least in some sports and among certain teams. "If this were a basketball game, we'd be behind about 98 to 2," says a former high-ranking official of the U.S. Olympic Committee (USOC), who asked not to be identified. Moreover, drug use by a small minority can fatally undermine the fundamental precept of athletic competition, in which victory goes to the contestant who best combines such attributes as strength, coordination, endurance, discipline and cunning.

"Sport is well aware it is losing the battle," says Don H. Catlin, director of the Olympic Analytical Laboratory at the University of California at Los Angeles. "Sports officials are terribly concerned about this matter. It tears at them."

The pall of drug use has grown darker in recent years as evidence has accrued that athletes in a variety of sports are increasingly turning to erythropoietin (EPO) and human growth hormone (hGH), both relatively recent arrivals in the world of sports. Like hundreds of other substances explicitly banned by the IOC, these two are effective and easy to obtain. They have surged in popularity because, unlike the other agents, EPO and hGH are undetectable with the technology that sports officials currently use to catch transgressors.

A BRIEF HISTORY OF CHEATING

EPO and hGH are just the latest gambits in a cat-and-mouse game that is more than four decades old. By 1954 some Olympic weight lifters in the Soviet Union and elsewhere were using muscle-building anabolic steroids, according to sports historians. The chemical games had begun: the cheaters were in the lead, and their opponents have never caught up. As the pharmaceutical industry blossomed, new forms of steroids, stimulants, hormones and red blood cell growth hormones flowed into the market. Most of the substances spur muscle growth; a few improve endurance; still others, known as beta blockers, slow the heartbeat, which lets sharpshooters or archers take steadier aim and helps a figure skater calm jangled nerves before a big performance.

Today the dishonest athlete can choose from an assortment of about 36 different anabolic steroids (among them a couple originally intended for veterinary use). Athletes get the drugs in different ways, and some observers maintain that it is not terribly difficult for an elite athlete to find a sports physician who is willing to break professional rules to assist an Olympian on a quest to glorify his or her country.

Cheating athletes have tapped biotechnological bounty with impressive swiftness and sophistication. Meanwhile the Olympic movement, along with all of international sport, has been turning to ever more advanced technologies in concerted if sporadic attempts to catch them. "It's almost like the cold war was," says David Joyner, chair of the USOC's sports medicine committee.

Formal drug testing for stimulants began at the Mexico City Olympic Games in 1968, a year after a British cyclist who had taken stimulants died of heart failure while competing in a televised stage of the Tour de France and eight years after several cyclists perished suddenly and similarly at the 1960 Olympics in Rome.

Not until 1975 did the IOC finally ban muscle-building anabolic steroids. Seven years later it added testosterone and caffeine to its list of forbidden substances. Testosterone, a key male hormone, plays an important role in muscle building. Anabolic steroids are just synthetic versions of testosterone, tweaked so they can be taken orally or so that they persist in the body.

A sensitive, reliable test for the anabolic agents did not debut until 1983, at the Pan American Games in Caracas, Venezuela. A German physician set up a lab in which the primary instruments were gas chromatographs married to mass spectrometers. The chromatograph in one of these combined units is basically an elaborate discriminator: it takes a sample that has been vaporized and separates it into its component substances. The spectrometer then weighs the fragments to identify the specific molecule they came from. The instrument, known as a GCMS, is the workhorse technology that testers rely on to this day.

BUSTED: Yuan Yuan, a Chinese swimmer, was escorted away by police on January 8, 1998, after she arrived at the Perth airport in Australia for a competition. Officials had found 13 vials of human growth hormone in a thermos she was carrying.

MIKE FIALA *AP Photo*

The use of the new technology in Caracas was not announced in advance to the competitors. As a result, 19 athletes tested positive for drugs at those games. More telling, many athletes—including a huge U.S. contingent—refused to be tested and left without competing. The next year, in 1984, GCMS was used for the first time in Olympic competition at the Los Angeles Games.

Sports officials, notably from East Germany and the Soviet Union (and subsequently Russia), were only mildly inconvenienced by the improved technology. Countries continued to operate elaborate programs that chemically enhanced hundreds or thousands of athletes and won hundreds of medals. At the 1988 Olympics in Seoul, for example, the Russian delegation reportedly operated a drug lab on board a ship docked in the harbor. The lab monitored Russian athletes to make sure they would not test positive for any banned substances. (Athletes on steroids simply stop taking them a few weeks prior to competition; continuing to exercise vigorously can retain for weeks the extra muscle mass.)

Members of the U.S. Olympic team, too, have been the subjects of disturbing allegations. Pat Connolly, a former U.S. Olympic women's track coach, told a Senate hearing in April 1989 that she believed that "at least 40 percent of the [U.S.] women's team in Seoul had probably used steroids at some time in their preparation for the games." It is worth noting that none of them tested positive in Seoul.

Although testers had a breakthrough at the 1984 Los Angeles Games with the GCMS, cheaters also made a major leap forward: blood doping. Weeks before the competition, eight of the 24 members of the U.S. cycling team had some of their blood removed and preserved. Their blood supply rebounded naturally over time. Shortly before competing they met in a southern California hotel and had their store of red blood cells transfused back into their system. Raising their red blood cell counts to abnormally high levels enabled their circulatory systems to carry more oxygen and thus improved their endurance considerably. The team went on to win a record nine medals before the doping was discovered, months later.

EPO: THE MODERN ERA BEGINS

Blood doping had begun years earlier, but the old transfusion method is no longer used. The practice became considerably more convenient when EPO became available in the late 1980s. A peptide hormone that stimulates the production of red blood cells in bone marrow, EPO is found naturally in the body. In 1985 the biotechnology firm Amgen introduced EPO produced by recombinant means to treat kidney dialysis patients and others.

Too much of a good thing, however, can be fatal. EPO has been blamed for the deaths of about 20 European cyclists since 1988. Although there is no hard proof that EPO caused the deaths, some doping experts believe the riders' blood may have thickened and clotted fatally after they took too much of the drug.

The full magnitude of the EPO problem, at least in cycling, became apparent for the first time during the 1998 Tour de France, cycling's premier event. During the race, police officers found cases of the drug in car trunks and in the hotel rooms of many cyclists. Seven teams were implicated; one withdrew, and another was expelled.

Today, despite more than a decade of sporadic research and development, several million dollars spent and intermittent promises by sports organizations, there is still no test that directly identifies the presence of EPO. Before major races, however, officials in cycling (and also in cross-country skiing) routinely test blood samples from all competitors. Those with a hematocrit, or red blood cell percentage, higher than 50 are banned from the race. A normal hematocrit is around 42. The policy has so far pre-

BANNED PERFORMANCE ENHANCERS AND THEIR EFFECTS

The International Olympic Committee bans drugs in several categories.
A few examples from each group, and their most common side effects, appear here.

Drug	Benefits	Side Effects	Notes
Stimulants			
Amphetamine, methamphetamine	Increases endurance; relieves fatigue; improves reaction times	Irregular heartbeat, false sense of well-being, irritability, nervousness, restlessness, trouble sleeping	Used to treat narcolepsy and Attention Deficit Hyperactivity Disorder
Caffeine	Increases alertness; reduces drowsiness; promotes endurance	Nervousness, irritability, sleeplessness, diarrhea, dizziness, fast heartbeat, nausea, tremors, vomiting	Brewed coffee per cup contains 40–180 milligrams; illegal urine levels are 12 micrograms per milliliter
Pseudoephedrine	In high doses, acts like amphetamines; narrows blood vessels	Increases blood pressure in patients who have high blood pressure	Decongestant (narrowing blood vessels decreases nasal congestion)
Salbutamol (albuterol)	Controls "bronchospasms" induced by exercise; opens up the lungs' bronchial tubes	Fast heartbeat, headache, nervousness, trembling	Used to treat or prevent symptoms of asthma, chronic bronchitis, emphysema and other lung diseases
Anabolic Steroids			
Androstenediol, androstenedione, 19-norandrostenediol, 19-norandrostenedione, nandrolone, stanozolol, testosterone	Increases strength, muscle mass and aggressiveness	Acne or oily skin, enlarged clitoris/penis, deepened voice, unusual hair loss or growth, psychological disturbances; in sexually mature males, enlarged breasts	Androstenedione is available over the counter in the U.S. but is illegal in most other countries
Clenbuterol	Increases strength and muscle mass	Tremors and heart palpitations (tachycardia)	Decreases exercise capacity in rats, presumably due to changed cardiac muscle structure and function
Diuretics			
Acetazolamide	Increases urine flow and volume; prevents or lessens high-altitude effects	Unusual tiredness or weakness, diarrhea, general discomfort, loss of appetite or weight loss	Anticonvulsant (for epilepsy); used to treat glaucoma
Bumetanide, chlorthalidone, hydrochlorothiazide, triamterene	Increases urine flow and volume, diluting drugs or decreasing weight for sports with weight categories	Makes skin more sensitive to sunlight	Used to treat high blood pressure (hypertension) or to lower the amount of water in the body
Masking Agents			
Bromantan	Supposedly masks the use of other drugs, presumably steroids	Unknown	Russian-developed "immunostimulator"; unavailable in West
Probenecid	Stops excretion of steroids for a few hours, decreasing urine steroid concentration	Headache, joint pain, redness or swelling, loss of appetite, nausea or vomiting (mild)	Used to treat chronic gout or gouty arthritis; improves functioning of penicillins
Peptide Hormones, Mimetics and Analogues			
Chorionic gonadotropin (hCG)	Elevates testosterone production in men	Breast enlargement, headache, irritability; in women: bloating, stomach pain; in boys: acne, rapid increase in height, pubic hair growth, enlargement of testes and penis	Used by women to promote conception or in vitro fertilization and by men to produce testosterone
Human growth hormone (hGH)	Decreases fat mass; thought to improve human performance	Diabetes; abnormal growth of bones and internal organs such as the heart, liver and kidneys; atherosclerosis; high blood pressure (hypertension)	Used to treat growth disorders and prevent AIDS-related weight loss
Erythropoietin (EPO)	Increases circulating red blood cells, carrying more oxygen to muscles	Oily skin, acne and muscle tremors; thickens blood, increasing chances of stroke, myocardial infarction and heart failure	Used for treating anemia in patients with kidney disease, cancer and HIV
Beta Blockers			
Atenolol, bisoprolol, metoprolol, nadolol, propranolol	Slows heartbeat, enabling archers or shooters to increase their "interbeat interval"	Slows cardiac response time; makes running difficult; makes skin more sensitive to sun and temperature extremes	Used with a diuretic to treat high blood pressure

Compiled by Naomi Lubick. *SOURCES: International Olympic Committee; Don H. Catlin, University of California at Los Angeles; Larry Bowers, University of Illinois; Mayo Clinic; National Institutes of Health* vented any more EPO-related fatalities during races, but it has done little to eliminate the drug from the cycling circuit. For example, the policy was in effect during the scandalous 1998 Tour de France, in which many dozens of riders are known to have used the drug.

Athletes in muscle sports such as weight lifting, sprinting, wrestling and short-distance swimming have their own options for obtaining an undetectable edge. Because hGH and testosterone are, like EPO, found naturally in the body, they can add muscle without leaving any incriminating molecules behind for the GCMS operators.

HGH is an astoundingly expensive steroid substitute. Yet its use was apparently rampant enough in Atlanta in 1996 to inspire some athletes to dub those Olympics the "hGH Games." Around that time, a Latvian company was doing brisk business harvesting hGH from human cadavers and selling it for athletic use. And as recently as February, police in Oslo apprehended two Lithuanians with 3,000 ampoules of black-market hGH, according to Gunnar Hermansson, chief inspector of the drugs unit of Sweden's National Criminal Intelligence Service. The cache was enough to supply about 100 athletes for a month.

Esters of testosterone are another essentially undetectable muscle builder. As their name implies, they consist of testosterone linked to an ester, both organic molecules. The ester acts to delay the loss from the body of the hormone, which would otherwise be metabolized in hours. In the body, neither the testosterone nor the ester arouses suspicion, because both are found there naturally.

Sports officials can, however, detect gross abuse of esters of testosterone. As part of a standard drug test, they examine the relative amounts in the athlete's urine of testosterone and epitestosterone, a hormone of uncertain function. In a normal Caucasian male, the ratio is about one to one. If the ratio is found to be six to one or greater, the IOC and other sports organizations declare the test positive and the athlete is sanctioned, unless he can prove that he is the rare (one in 2,000) male who has such a high ratio naturally.

The situation is far from ideal. Doping experts say that some athletes use transdermal patches and other controlled delivery methods to boost the level of testosterone in their blood significantly while staying below the six-to-one ratio. Another problem is that the current practice does not treat different races equally: on average, Asians have lower levels of testosterone than blacks or Caucasians do, so it is considerably more difficult for an Asian athlete to dope himself beyond the six-to-one limit.

THE CHEATER'S LAST LOOPHOLE

Even if sports officials decide to sanction an athlete based on an elevated testosterone ratio or some other test result, they are often stymied by a recourse that increasingly seems like the abusing athlete's ace in the hole: the adjudication process. Suppose an athlete wins an Olympic medal but then tests positive for a banned substance. If the IOC decides to strip the athlete of his medal, she can appeal to the Court of Arbitration for Sport. The court must then decide within 24 hours whether to uphold or overturn the sanction.

The court, set up in the mid-1980s, comprises representatives from the IOC, the National Olympic Committees (NOCs), the International Federations (IFs) and representatives of the athletes. The NOCs are the agencies that govern and coordinate a country's Olympic representation and help train its athletes (the USOC is an example). The IFs organize and oversee amateur competition in a specific sport. The one group of people the court has never seen fit to include are those with formal expertise or credentials in the pharmacology or physiology of performance-enhancing drugs.

In its short history the court has leaned toward exoneration, unless the case is simple and compelling in the extreme. In Atlanta, tests of seven ath-

JAN BAUER *AP Photo*

DRUG CZAR: Manfred Ewald, the former East German sports director, went on trial in May for his involvement in a state-sanctioned program that drugged hundreds if not thousands of athletes, most without their knowledge or consent.

letes—among them two Russians who had won bronze medals—indicated that they had used a drug called Bromantan. The IOC, which now regards the drug as both a stimulant and a masking agent, decided to disqualify the athletes. The case went to the Court of Arbitration, where the athletes' attorneys contended that the Bromantan merely strengthened the athletes' immune systems and helped them deal with the heat of summer in Atlanta. The argument swayed the court enough for it to overturn the disqualification.

The case was important because it suggested to many observers that the burden would fall on the prosecution to prove each case beyond a reasonable doubt. "A lot of people seem to have decided that the criminal standard is the one that should apply," says Larry D. Bowers, head of the drug-testing laboratory at the Indiana University School of Medicine. Unfortunately for prosecutors, the complexity of the biochemical evidence often leaves defense attorneys enough room to generate at least a trace of doubt in adjudicators' minds.

GETTING THROUGH THE NETS

Although it is undoubtedly nice to know it is there, an athlete-friendly adjudication process is something that most clever drug users will not need. Various administrative and logistical factors conspire to create holes in the nets set up to snare cheaters.

Because of its position at the pinnacle of amateur athletics, the IOC is often regarded as the central figure in high-stakes drug testing. In reality, the situation is far more complicated. The IOC is responsible for drug testing during the Olympic Games, but that is only a small fraction of the testing performed on elite amateur athletes. At each Olympics, the medal winners at every event submit urine samples at doping-control stations immediately following their events. One or two nonmedalists are also generally tested at random. Athletes are selected arbitrarily, too, at preliminary events and from teams in final and semifinal rounds. In all, just under 20 percent of all athletes are tested during an Olympiad.

Officially, over the past 30 years only 52 athletes have been caught and sanctioned for using drugs in Olympic competition. Not even the staunchest Olympic booster thinks that only 52 athletes have cheated in the past three decades; it is now well known that far more than 52 competitors from the former East Germany alone took drugs and eluded detection. Even today the low rate of detection is thought to reflect the fact that the games are the one time when an athlete can be sure of being tested if he or she does well. "These days you have to be a total idiot to test positive at an event," says Bob Condron, a spokesman for the USOC.

This and other factors shift attention to the role of the IFs and the NOCs in drug testing. The IFs oversee drug tests at major non-Olympic competitions in the specific sports they administer. But it is the NOCs that arguably have the most crucial drug-testing role in all of amateur sports. They are responsible for testing athletes throughout their training—the period when almost all performance-enhancing substances, other than stimulants, are taken. The NOCs also test at national championships and at international competitions in their respective countries. Yet the world's many NOCs approach their drug-testing duties with varying degrees of rigor and vigilance.

Whereas tests by the IOC during Olympic Games are anticipated by athletes, the NOCs have the power to test athletes with little advance notice—or, ideally, no notice at all. Until recently, most NOCs have taken advantage of this opportunity relatively infrequently, if at all. And when they did, they often performed short-notice tests, in which the athlete was given 48 hours' warning that he or she would be tested. The tip-off would often enable a cheating athlete to take steps to expunge or mask the telltale chemicals. "A lot of athletes can clear their systems in 24 hours," explains Baaron Pittenger, head of the USOC's antidoping committee.

According to Catlin, athletes can try at least 13 different diuretics, which stimulate urination that dilutes incriminating chemicals and speeds them out of the body. A drug called probenecid has been used to interfere with the excretion of steroids. A few athletes, Catlin adds, have even endured the excruciatingly painful process of using a long needle to put untainted urine into their own bladder. Diuretics and probenecid are no longer as effective as they once were, because testers now routinely check for them.

Some NOCs are finally making more use of no-advance-notice tests. Joan Price, senior manager of drug testing for the USOC, says the organization performed 1,345 no-advance-notice tests in 1999, up from about 800 the previous year. It carried out 4,024 additional tests during competitions. For both the no-advance-notice tests and the ones performed during competitions, the rate of positive results was between 3 and 4 percent, she says.

The main reason why NOCs have been slow to pursue no-advance-notice testing more rigorously is that it is a relatively expensive, travel-intensive process. In some cases, it requires paying for a tester to travel hundreds or thousands of miles to meet an individual athlete.

DOES THE IOC MEAN BUSINESS?

Although the NOCs have the power to be the main bulwark against the use of performance-enhancing drugs, the IOC remains firmly entrenched at the center of the antidrug movement. Some reasons are practical: the organization plays a key role in formulating drug-testing policy, sets the standards for drug-testing laboratories worldwide and is also the largest single source of funding for drug-testing research. Other reasons have more to do with perceptions. Because the IOC is the highest Olympic governing body, its moves in the fight against performance enhancement greatly influence how the broader Olympic movement regards the effort.

BLOOD-DOPING BREAKTHROUGH? Finnish long-distance runner Lasse Viren, reportedly among the first to boost his red blood cell count by artificial means, was victorious in the 5,000- and 10,000-meter races at the 1976 Olympics in Montreal.

TONY DUFFY *Allsport*

Unfortunately, the IOC's actions over the past two or three decades have repeatedly left observers questioning the organization's commitment. At Los Angeles in 1984, papers describing between five and nine positive drug tests were taken from a safe and shredded shortly after the end of the games. The athletes involved could therefore not even be identified, much less sanctioned. The records had been secured in a hotel room used by Prince Alexandre de Merode of Belgium, chair of the IOC's Medical Commission, which oversees antidrug activities. De Merode later said he believed the papers were taken mistakenly and destroyed by members of the Los Angeles Olympic Organizing Committee. (He declined repeated invitations from Scientific American Presents to be interviewed for this article.)

Months after the 1996 Atlanta Games, it came to light that four test results indicating use of the steroid methandienone were never acted on. The results were obtained with an extremely sophisticated high-resolution mass spectrometer (HRMS), which was being used for the first time during Olympic competition in Atlanta. The HRMS, which costs a cool $860,000, has about 10 times the resolution of a conventional GCMS. The greater sensitivity means that the high-resolution unit can often detect steroid metabolites in a urine sample more than a month after the athlete has stopped taking the drugs, as opposed to perhaps two or three weeks later with a conventional GCMS.

After the drug testers reported the four positive results to the IOC toward the end of the games, the IOC decided not to take action on them. Having been stung by the Bromantan experience just a few days before, the organization apparently decided it could not win a case based on evidence from a machine that some regarded as experimental.

Why would the IOC not want to vigorously root out and prosecute drug use at every opportunity? Some critics, including former athletes, have speculated that a large number of drug busts at an Olympics would undermine public support and enthusiasm for the games by tarnishing the sheen of fair competition. It is increasingly hard to accept that notion, though, given that the Tour de France has hardly suffered despite a scandal only two years ago that was about as bad as can be imagined.

WHAT'S DIFFERENT NOW?

As the Sydney Olympics get under way, a comparison between the current state of Olympic drug testing with what it was on the eve of the 1996 Atlanta Games is revealing—and perhaps a little depressing. The tests, technology and administrative procedures available to sports officials are essentially unchanged. And few antidrug officials were satisfied with the way things turned out in Atlanta. After all, these were the Olympics known as the hGH Games, in which 11 athletes are known to have tested positive for banned substances and suffered no consequences.

There may be one small but potentially significant technological advance for the antidrug forces. Officials may make more use of a technique known as carbon isotope ratio detection to determine whether competitors have taken synthetic testosterone. The test would be a vast improvement over the current method—the dubious search for a testosterone-to-epitestosterone ratio greater than six to one.

The carbon isotope ratio technique is telling because drug companies use plant sterols from soybeans to produce synthetic testosterone. Natural testosterone in the body comes from cholesterol. Compared with carbon atoms in natural testosterone, the carbon atoms in a sample of synthetic testosterone have a slightly lower ratio of the carbon 13 isotope to carbon 12. By measuring this ratio, researchers can determine if some of the carbon in a testosterone sample originated outside the body.

Researchers did have a carbon isotope ratio detection system in Atlanta and also at the 1998 Winter Games in Nagano, Japan, but the machines were used only experimentally. At press time, the IOC was evaluating whether it would incorporate the machine into its routine tests.

WHITHER WADA?

Even if there is a test for testosterone in Sydney, there will be none for the two other natural hormones, EPO and hGH. The reasons why are complex [see "All Doped Up—and Going for the Gold," News and Analysis; Scientific American, May]. The short, simplified answer is that the IOC, unwilling to put its full support behind experimental tests that might not withstand legal challenge in the Court of Arbitration, opted to plow its resources into a new antidrug bureaucracy, the World Anti-Doping Agency (WADA).

WADA was formed to bring together, for the purpose of fighting the spread of performance-enhancing drugs, representatives of the IOC, the IFs, the NOCs, Olympic athletes, 12 national governments, and bodies from various international organizations, such as the United Nations. Perhaps not coincidentally, its formation was announced to great fanfare in February 1999 as the reverberations from the Salt Lake City Olympics bribery scandal were reaching a crescendo at the IOC. WADA's director is Richard W. Pound, an attorney, a former Canadian Olympic swimmer and a longtime IOC vice president who is often mentioned as the favorite to succeed Juan Antonio Samaranch as IOC president.

According to Pound, the IOC has pledged to spend $25 million over two years to get WADA up and running. It hopes that by then ongoing contributions will be coming from additional sources, such as national governments and international organizations. In explaining the need for WADA, Pound notes that the fight against performance-enhancing drugs is now a sprawling effort, heavily dependent on the work of the NOCs, IFs and, in some cases, customs agents and national police forces. WADA will be a single place where all those parties can plot strategy and find common ground among their agendas. But getting so many agencies to cooperate will probably be more challenging than it might initially seem. Although antidrug efforts are decades-old, the Olympic movement, including the NOCs and the often recalcitrant IFs, agreed on a single, uniform antidoping code only this past January. Pound also expects that with its diverse membership base, WADA will be able to assume a role as a larger, more effective platform for directing and funding research and development on drug tests.

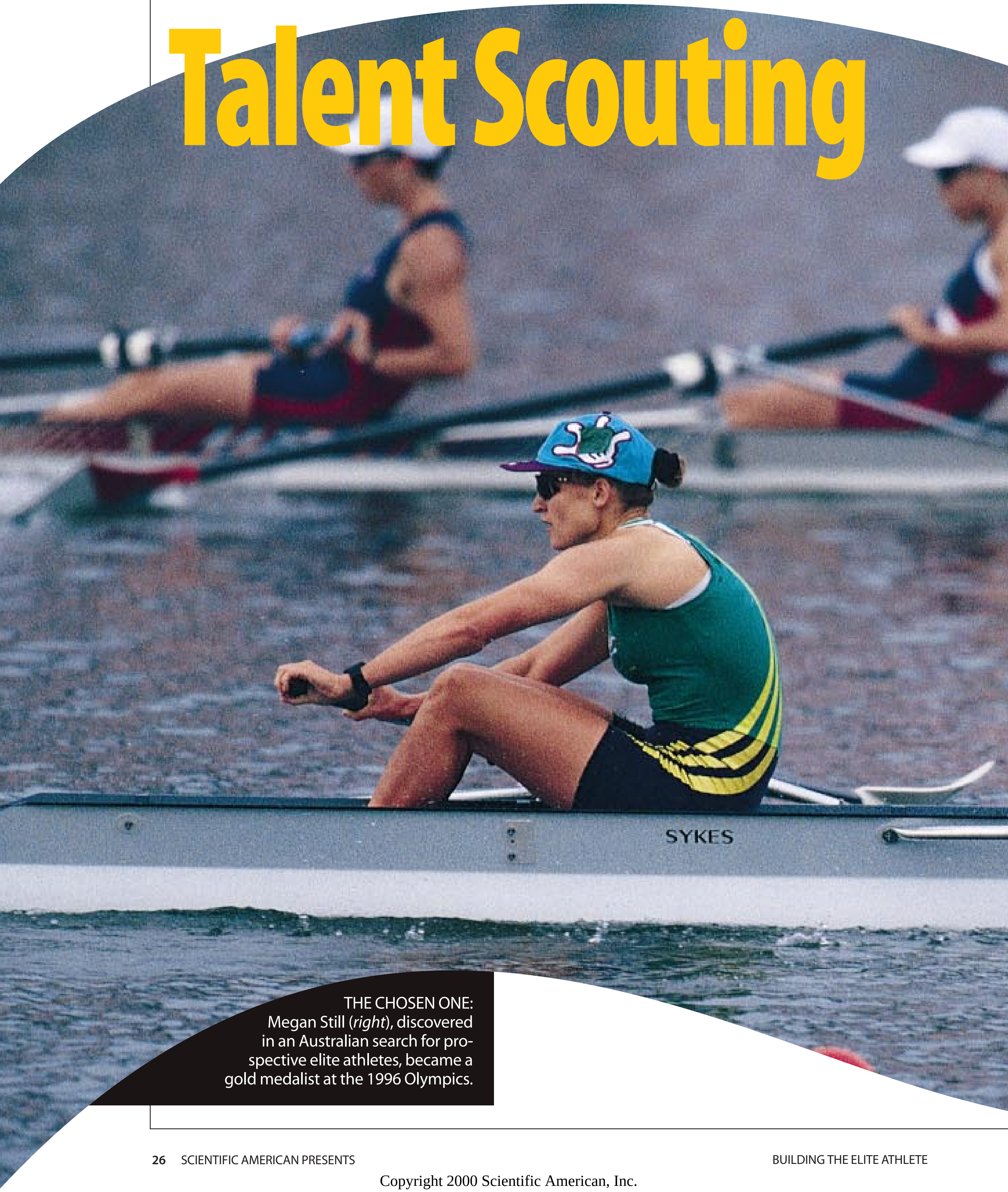
It is possible, however, that drug-testing research as it is practiced today is nearing a twilight of sorts. In the near future dopers will take their perennial, escalating struggle with their keepers to a new level. Within a decade, perhaps, athletes will be able to inject themselves with genetic vaccines that will induce their body's own protein-making apparatus to add muscle mass or increase EPO (or both). In fact, in an overlooked experiment reported in 1997, Eric C. Svensson and others at the University of Chicago successfully used a genetic technique to boost the levels of EPO in the blood of some adult cynomolgus monkeys. The researchers subsequently measured hematocrits as high as 70 in the monkeys. (To keep the monkeys alive, the researchers diluted their blood.) When such genetic vaccines become available to athletes, the chemical games will be pretty much over. It will be difficult, if not impossible, for testers to distinguish inserted fragments of DNA from the DNA that was already there.

"When you come to a method where you are increasing proteins in the cells genetically and directly, you'll have to have much more sophisticated detection techniques," says Mats Garle, scientific director of the IOC-affiliated Doping Control Laboratory at Huddinge University Hospital in Sweden. After a moment's reflection, he admits, "Maybe we'll never get a solution to that problem."

FURTHER INFORMATION

ANABOLIC STEROIDS IN SPORT AND EXERCISE. Edited by Charles Yesalis. Human Kinetics Publishing (in press).

Toward Molecular Talent Scouting



THE CHOSEN ONE:
Megan Still (*right*), discovered in an Australian search for prospective elite athletes, became a gold medalist at the 1996 Olympics.

Scientists are engaged in a frustrating search for genes to identify future Olympians

by Gary Taubes

Thirteen years ago the Australian Institute of Sport (AIS) set out to level the Olympic playing field, to make it possible for a country of fewer than 20 million inhabitants to compete against nations with 10 or 50 times the talent pool. The result was the national Talent Search Program, which would scour the high schools of Australia for 14- to 16-year-olds who had the potential to be elite athletes and might not even know it. Once identified, these kids would be given the opportunity to engage in the sports in which they were most likely to excel, given their physical attributes and skills.

The program began in 1987 by searching for rowers to compete in a sport in which the Australians had failed to qualify a single athlete for the 1988 Olympics. The Talent Search team described the physical and physiological characteristics that appeared to differentiate elite rowers from their less successful competitors and then went off to test Australian high school students and se-

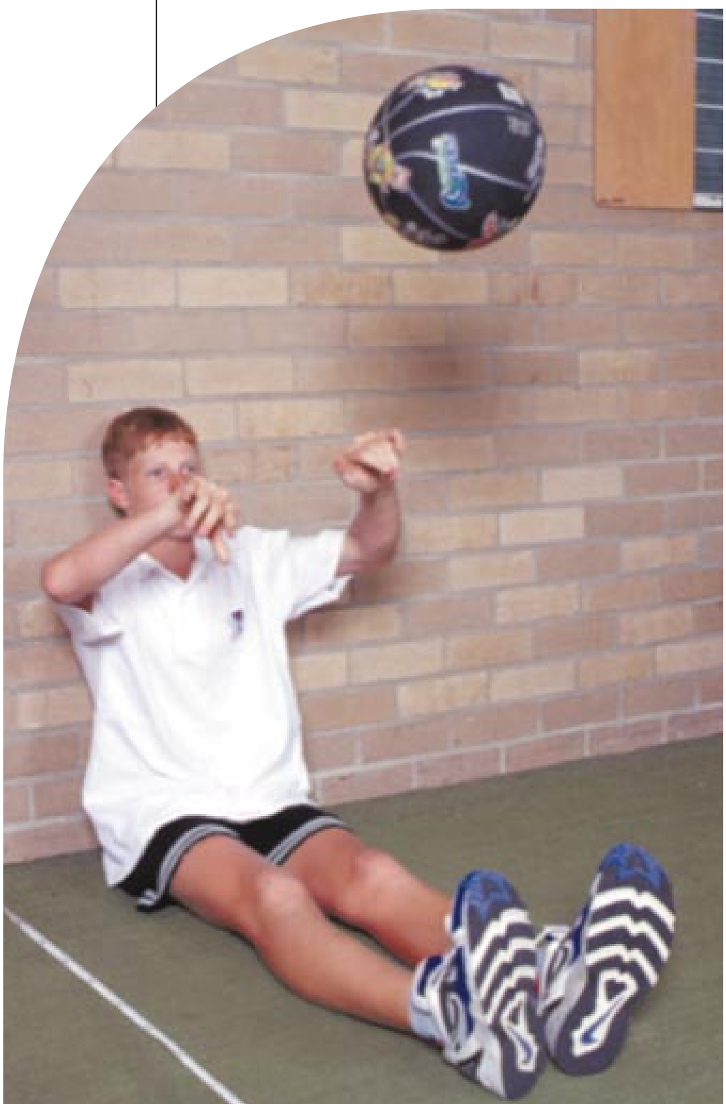
SPORT. THE LIBRARY

SELECTION PRESSURES: Teenagers in Australian high schools went through a battery of tests to determine their potential to become top athletes.

lect those who possessed the winning attributes—people who were tall with broad shoulders relative to their hips, long limbs, good musculature and a relatively high level of both strength and endurance. That the program and the philosophy could pay off was demonstrated in the 1996 Atlanta Olympics, when Megan Still took home a gold medal in women's rowing. Still had been running track as a 16-year-old before Talent Search handed her an oar.

TRAINABILITY GENES

In 1994 Talent Search was extended to eight different sports, from cycling and canoeing to water polo and weight lifting, and the program's researchers concocted a series of tests to measure coordination, endurance, strength and aerobic fitness. That left one critical attribute, however, for which they've yet to develop a test: how to differentiate the young athlete who will improve greatly from one who has, in effect, peaked. "We know that you can give two people the same training program, and one will respond to it with enormous improvement in performance capabilities, and the other will show hardly any improvement at all," says Allan Hahn, director of the physiology program at the AIS.



Over the years, researchers have demonstrated that the difference in "trainability" is mostly in the genes: some of us have an innate ability to respond to exercise and others don't, and the ability runs in families. So the AIS has launched a project to identify those genes and put them to work. "The aim is to see if we can maybe use some of these genetic characteristics to work out who will respond to a particular training program," Hahn comments, "although it is a very long-term goal."

Call it the search for performance genes. Someday researchers hope to pinpoint those genes that not only ensure trainability but perhaps endow athletes with the flashing speed of a sprinter or the endurance of a marathoner or that differentiate a power lifter from a power forward. In the past decade researchers have found at least two gene mutations—one in horses and one in humans—that will bestow a winning edge on those who possess them, but they have yet to locate those genes in the general population that differentiate winners from losers or the trainable from the untrainable.

Meanwhile the bulk of the research is done not in pursuit of Olympic glory but with the hopes of curing or ameliorating chronic diseases and the deterioration that comes with aging. The logic: find the genes that are crucial to muscle growth, and you have a handle on how to restore muscle growth to the elderly, to forestall the physical frailty and debilitation that comes with aging. Identify a gene that explains why some individuals are especially efficient at putting oxygen to work in their cells, and you might be on the way to creating a drug that makes cells work more efficiently with the limited oxygen and nutrients those cells receive when heart disease or cancer strikes.

AN EQUINE SCHWARZENEGGER

That a single gene can make a difference was demonstrated unambiguously by a quarter horse, aptly named Impressive. Purchased at the Indiana State Fair in 1969, Impressive went on to become the most famous progenitor of quarter-horse show winners for decades to come. He had the perfect physique, the ideal blend of muscle mass and tone for his frame, which is what it takes to win in quarter-horse competitions. By 1992, 13 of the top 15 quarter horses in the world were his descendants.

Impressive, however, had a single flaw in a single gene—a one-letter abnormality in the three billion letters that constitute the horse genome. The result of this mutation was a defect in the molecular channels that controlled the flow of sodium into and out of Impressive's muscle cells. It was discovered because this flaw also induced a type of temporary paralysis often fatal to the afflicted horses. On the

PHOTOGRAPHS COURTESY OF THE AUSTRALIAN NATIONAL TALENT SEARCH UNIT other hand, it led directly to the extraordinary musculature of Impressive and his progeny. "This caused some furor within the horse community," explains geneticist Eric P. Hoffman of George Washington University, "because this single nucleotide change definitely makes you win. There is absolutely no question. You look like Arnold Schwarzenegger in a horse if you have this single base change."

Hoffman and his colleagues have now discovered a host of genetic mutations in animals and humans that lead to excessive musculature. Muscle growth is spurred first by damage to the muscle cell membranes caused, for example, by lifting weights. The muscle responds to damage by growing back stronger and larger. These mutations result in muscle cells that are more easily stimulated to contract and so, in effect, are constantly exercised—as is the case with the sodium channel defect of Impressive and his offspring in muscle cells that are easily damaged and so more easily spurred to grow back stronger.

One example is Duchenne's muscular dystrophy, the most common lethal childhood disorder. In Duchenne's, a single genetic defect results in the complete absence of a protein, called dystrophin, that is critical to the structural integrity of muscle cell membranes. In cats, the absence of the dystrophin protein is relatively benign but still leads to Schwarzenegger-esque musculature. "A lot of their muscle groups are double the size of [those of] normal cats," Hoffman remarks. And children lacking the dystrophin protein often "look like professional body builders at five and six, and they don't lift any weights." In children, however, the muscle soon turns into scar tissue, resulting in the gradual wasting away that characterizes the disease in its later stages. "It's like the muscle tries to keep growing back and [dies and grows] back and, in time, just gives up." In less severe forms of muscular dystrophy, such as Becker muscular dystrophy, the dystrophin gene is defective but not missing. The result often manifests itself as the abnormal muscle growth without the fatal consequences. "We found patients with [this abnormal] dystrophin," Hoffman says, "who are professional athletes. Some are professional tennis players; some are weight lifters; some are quarterbacks on football teams."

Now Hoffman and his colleagues are comparing the genes of average individuals with those of world-class body builders, weight lifters and football players to see if the genes that code for dystrophin and other structural proteins of the muscle cell membranes play an important role. Specifically, they wonder whether these athletes have a particular variation in the gene—as opposed to a rare mutation—that might predispose them to muscular development and lead to success in their chosen events. In another study, Hoffmann and his collaborators are putting 1,600 students through an exercise program to see if those who come out of it with extraordinary muscle growth will turn out to share the same variants of specific genes. "Hopefully," he observes, "we'll find a lot of muscle strength and size genes out of a large study like this."

ELIMINATING COUCH POTATOES

While Hoffmann and his colleagues pursue the genetics of musculature, the bulk of the research in performance genes aims at tracking down those involved with endurance performance, if for no other reason than that athletic endurance correlates well with a physiological characteristic known as maximal oxygen uptake. This is your body's capacity to take in oxygen and put it to work in your muscles, and it is easy to quantify. "We know what we are measuring here," says Claude Bouchard, a geneticist and exercise physiologist who directs the Pennington Biomedical Research Center in Baton Rouge. "This is not the case, for example, in a sport that requires a lot of coordina-

IMPRESSIVE: The descendants of this quarter horse, which bore a genetic mutation that gave it extraordinary musculature, accounted for 13 of 15 top show winners by 1992.

DON TROUT

tion—basketball or archery or whatever—where we don't have a good laboratory measurement." Elite endurance athletes have a maximal oxygen uptake twice as high as that of the rest of us and perhaps three times that of elite couch potatoes.

This ability to use oxygen efficiently is determined by an enormous number of physiological variables, from the volume of blood that the heart can pump in and out to the efficiency with which the body can convert oxygen from the blood into fuel that powers muscle motion. As with muscle growth, however, there is one outstanding example that genetic mutations can succeed in providing a winning edge. In this case it's a mutation in a gene that codes for a protein known as EPOR, or the erythropoeitin receptor.

Erythropoeitin is a growth hormone that regulates the production of red blood cells, which carry oxygen through the blood to the muscles. EPOR is the protein with which erythropoietin interacts to initiate the process of red blood cell production. In this type of mutation, the EPOR protein is truncated. It can still turn on in response to erythropoeitin, but turning off is a problem. Individuals with this rare mutation generate an abnormal amount of red blood cells. This excess should give them an advantage in endurance sports, in which keeping oxygen flowing copiously to the muscles is critical.

That it does so was realized a decade ago, when Finnish researchers identified an entire family with the EPOR mutation, several members of which were championship endurance athletes, including one Olympic gold medalist, cross-country skier Eero Maentyranta. The Olympic champion, says Gregory D. Longmore, a biologist at Washington University, turned out to have an extraordinarily high red blood cell count, higher than could be achieved artificially by athletes who enhance their red blood cell count by injecting themselves with erythropoietin. "[The erythropoeitin receptor gene] is clearly a performance-enhancing gene," Longmore says.

CONTRADICTORY EVIDENCE

But researchers have been unable to show unambiguously that naturally occurring variations in EPOR or any other genes confer athletic advantages that might be predicted in advance through genetic testing. This is trickier than it might seem, as illustrated by the results so far of the two largest studies in the field. One, the Heritage Family Study, is a collaboration of four universities and Bouchard's Pennington center. The Heritage researchers recruited 200 families, encompassing some 750 sedentary subjects. They put them through a rigorous training program and then looked for genes that might relate to trainability, in this case the ability to increase maximal oxygen uptake with exercise. The second study, known as GENATHLETE, was begun 15 years ago by Bouchard and an international collaboration. The GENATHLETE researchers banked the DNA from more than 350 male Olympic-caliber endurance athletes and 350 sedentary controls, assuming that if any particular gene variants or mutations were critical to elite endurance performance, they would show up more frequently in the Olympic DNA than in that of the sedentary controls.

The Heritage researchers have been able to isolate four chromosomal regions—comprising millions and millions of base pairs of the double helix of DNA—that appear to be linked to maximal oxygen uptake while at rest among these sedentary individuals and another five different regions that are linked to trainability. When they tested specific genes, however, the results were discouraging. "We've probably looked at about 40 different genes," Bouchard says, "and we have a few we can clearly exclude." The GENATHLETE researchers have tested 30 candidate genes and come up effectively empty. "Nothing so far is striking," Bouchard says. As for EPOR, it seemed to show some small relation to trainability in the Heritage study but no relation to elite athletic performance in GENATHLETE.

The most controversial research and the most highly publicized candidate for a performance gene is one known as ACE, which stands for angiotensinconverting enzyme. It appears to play a role in regulating blood pressure, cell growth and the growth of heart muscle. In the early 1990s French researchers discovered that the ACE gene can be found in the general population in two distinct variations: one with an extra fragment of DNA (called the Insertion, or I, variant) and the other without it (called the Deletion, or D, variant). The two variants evidently influence the amount of ACE that can be found in tissue. Individuals with two I variants, one from their mother and one from their father, have significantly less ACE activity than do individuals with one I and one D, who in turn have less ACE activity than do individuals who have two D variants.

At University College London, physiologist Hugh E. Montgomery and his colleagues studied the effect of ACE variants first on young army recruits, then on elite endurance runners and finally on high-altitude mountain climbers. They found that individuals with two I variants (known as II) were, on average, more efficient at endurance exercise than either ID or DD individuals were and also seemed to be more trainable. Their bodies became considerably more efficient with exercise.

All this information strongly indicates that if you want to be an endurance athlete, it might help to check your ACE genes first and see if you have two I variants. Indeed, when Australian researchers from the University of Sydney compared Olympic rowers with the Australian population at large, they found that the II variant was overrepresented in the rowers. The Australian and English results might have settled the issue of ACE as a definitive performance gene, but several studies since, including GENATHLETE and Heritage, have not confirmed it. If anything, Bouchard says, the Heritage results suggest the opposite of the English and Australian results—that the DD variant is more common in individuals who respond well to exercise. To Bouchard, the idea of ACE as a performance gene is at best controversial and at worst wrong.

Most researchers in this field are confident that unambiguous performance genes will eventually be found, but they expect that the search will be difficult and that the benefit of having particular variants of these genes, unlike the rare mutations, will be very subtle. After all, even the simplest biological systems are excruciatingly complicated, full of protective redundancies and regulating mechanisms. University of Missouri biologists Marc T. Hamilton and Frank Booth recently demonstrated that some 100 genes are involved in regulating an activity as basic as taking the weight off your legs—at least in mice. It's what the Missouri researchers call an unloading experiment, which is the opposite of lifting weights and a much easier experiment to do with mice. They freed the rear legs of the mice from their usual job of supporting the body's weight. "Within 12 hours," Booth asserts, "almost 100 different genes either turned on or off. It's kind of striking—it means you only have to lie down for 12 hours and you'll see huge changes in gene expression."

This result strongly implies that even if researchers could make sense of what all these 100 genes are doing, they would find that no single gene is making a crucial difference. Rather they are all having some small interrelated effect. And that's just for the equivalent of lying down for 12 hours—which, last we heard, was not an Olympic sport.

GARY TAUBES is a science writer based in California.

FURTHER INFORMATION

FAMILIAL RESEMBLANCE FOR VO_2MAX IN THE SEDENTARY STATE: THE HERITAGE FAMILY STUDY. Claude Bouchard et al. in *Medicine & Science in Sports & Exercise,* Vol. 30, No. 2; February 1998.

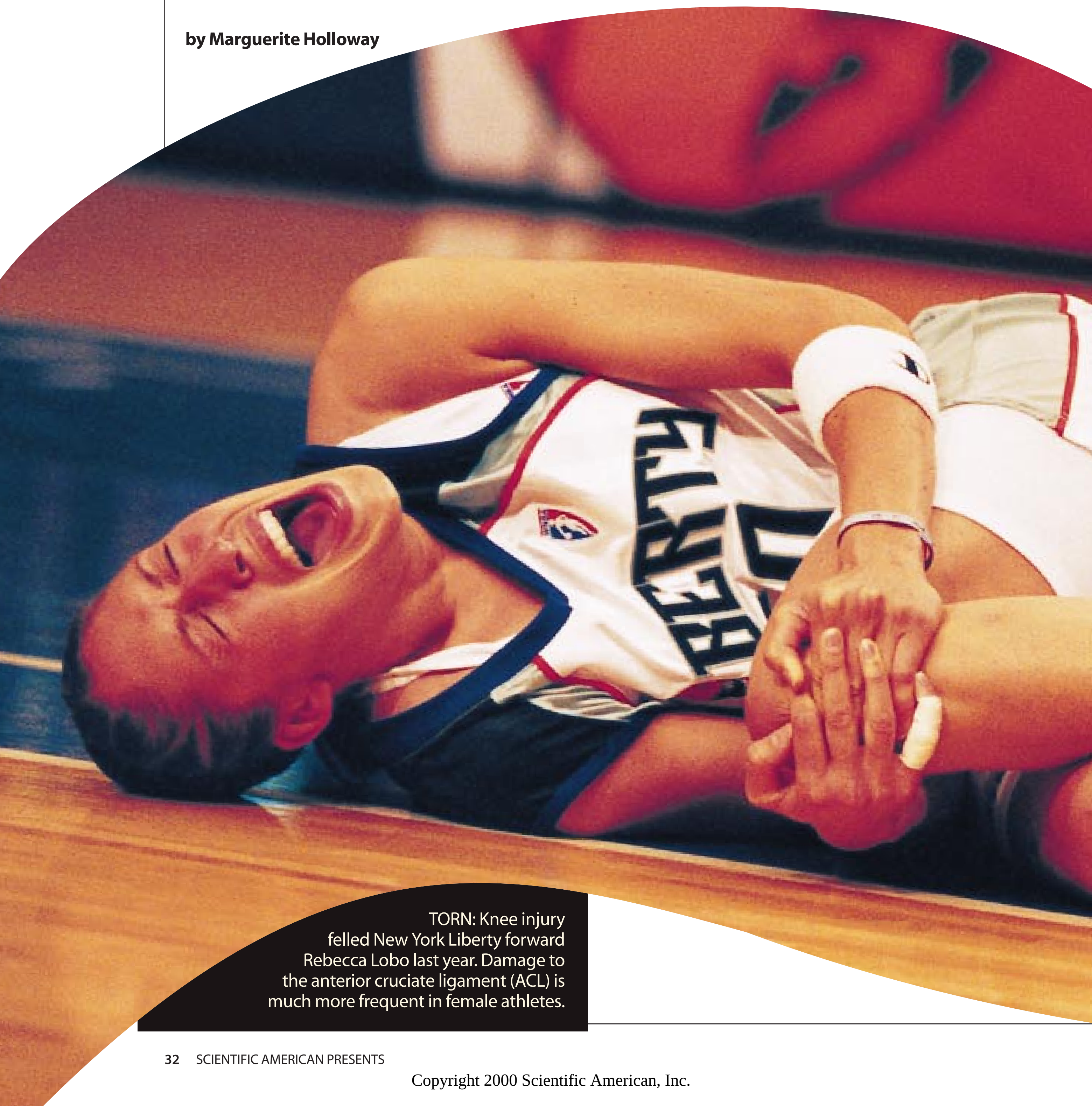
FATAL BUILD: A child with Duchenne's muscular dystrophy looked like a professional body builder, but signs of muscle wasting were already present.

LUCKY FLAW: Olympic cross-country skier Eero Maentyranta came from a Finnish family with a mutation that gives its members unusually high counts of oxygen-bearing red blood cells.

The Female Hurt

Women are more vulnerable than men to certain injuries and may not be getting proper treatment for them

by Marguerite Holloway



TORN: Knee injury felled New York Liberty forward Rebecca Lobo last year. Damage to the anterior cruciate ligament (ACL) is much more frequent in female athletes.

I don't want to hear a bunch of thuds," bellows Deborah Saint-Phard from her corner of the basketball court. Several dozen young women and girls, some barefoot, some in jeans and tank tops, some in full athletic regalia, look sheepish. They jump again, trying to keep their knees slightly bent and facing straight forward, trying to make no noise when their feet hit the floor. "I can hear you landing," Saint-Phard nonetheless admonishes, urging them into a softer touchdown. "Control your jump."

Saint-Phard is a doctor with the Women's Sports Medicine Center at the Hospital for Special Surgery in New York City. She and several colleagues have traveled to this gymnasium in Philadelphia for "Hoop City"—a National Collegiate Athletic Association (NCAA) event—to teach young women how to jump safely. Female athletes, particularly those playing basketball, volleyball and soccer, are between five and eight times more likely than men are to injure their anterior cruciate ligament, or ACL, which stabilizes the knee. Some 20,000 high school girls and 10,000 female college students suffer debilitating knee injuries each year, the majority of which are ACL-related, according to the American Orthopedic Society for Sports Medicine. Tearing the ligament can put an athlete out of the game for months, if not forever.

"This is a huge public health problem for women," says Edward M. Wojtys, an orthopedic surgeon at the University of Michigan. "Fourteen- to 18-year-olds are subjected to injuries that many of them will never recover from, that will affect whether they can walk or exercise at 40 and 50." For this reason, physicians are placing new emphasis on teaching female athletes how to jump in such a way that they strengthen their knees and protect their ACLs. "We have to get them when they are young," Saint-Phard says.

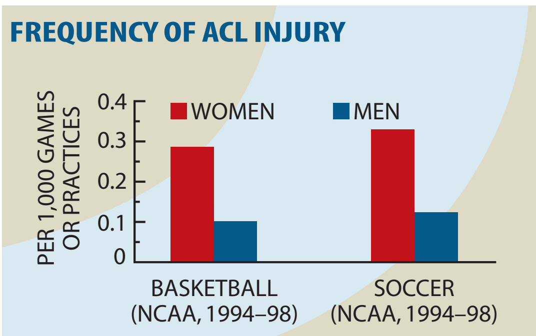
Torn ACLs are just one of the medical problems that plague female athletes. Injuries and ailments that occur with higher incidence in women than in men are garnering more attention as women enter sports in record numbers—not only as Olympians and professionals but for fitness and recreation. Today 135,110 women participate in collegiate athletics, according to the NCAA, up from 29,977 in 1972. The number of girls playing high school sports has shot up from 294,015 to 2.5 million in the same time frame. As a result, re-

PAUL SUTTON *Duomo*

searchers, physicians and coaches are increasingly recognizing that girls and women engaged in sports have some distinct medical concerns.

This makes perfect sense. Women's bodies are shaped differently than men's, and they are influenced by different hormones. They may be at greater risk not only for ACL tears but for other knee problems, as well as for certain shoulder injuries. Women are also uniquely threatened by a condition called the female athlete triad: disordered eating habits, menstrual dysfunction or the loss of their menstrual cycle, and, as a consequence of these two changes, premature and permanent osteoporosis. "We are seeing 25-year-olds with the bones of 70-year-olds," Saint-Phard says.

Although the passage of Title IX legislation in 1972 required that institutions receiving federal funding devote equal resources to men's and women's sports, it has taken a while for the particular needs of female athletes to emerge. As an example, Wojtys points to the ACL: "It took us 15 to 18 years



SOURCE: "Anterior Cruciate Ligament Injury Patterns," by Elizabeth Arendt et al., *Journal of Athletic Training*, June 1999

to realize that this problem existed." Women entering sports even a decade and a half after Title IX received less care from coaches and physicians than male athletes did, says Saint-Phard, who competed in the 1988 Olympic shot-put event. When she was in college, she recalls, "the men's teams got a lot more resources and a different level of coaches than the women's teams."

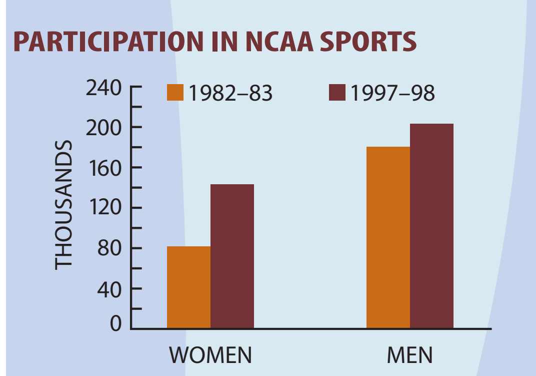
And today even those conditions that are increasingly well recognized as more problematic for women are not fully understood, and their etiology and treatment remain controversial at times. "There is not enough awareness of the differences," says Regina M. Vidaver of the Society for Women's Health Research. For most of the people treating sports injuries, she explains, "their predominant history is with men."

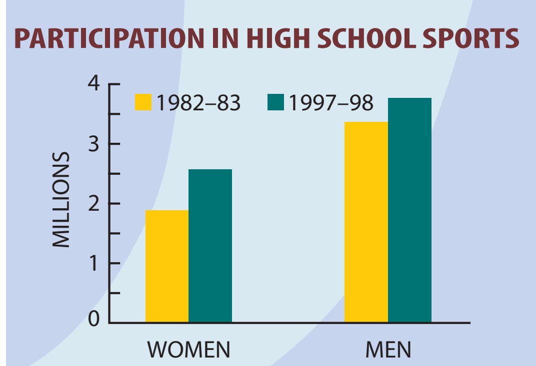
A spate of studies in the past few years on the ACL and the triad have made clear the need for specialized research and care for women. And the medical field seems to be responding accordingly. The Women's Sports Medicine Center is currently the only one of its kind in the U.S., but it won't be alone for much longer. This year the University of California at Los Angeles will open a center devoted to the medical care of female athletes, and Saint-Phard and her colleagues have had inquiries from universities wanting to start similar programs in Baltimore and Detroit, as well as in Florida, Texas, North Carolina and Tennessee. In addition, this autumn the National Institute of Arthritis and Musculoskeletal and Skin Diseases will solicit research proposals on women and sports—with an emphasis on the long-term consequences of exercise at all levels of participation. This area of medical inquiry is only a beginning, says the institute's Joan A. McGowan. "When you want research in a certain area, you can't just order it up, you have to grow it."

TEARING INTO ACL INJURIES

The most obvious musculoskeletal difference between men and women is the breadth of their hips. Because a woman's pelvis tends to be wider, the muscles that run from the hip down to the knee pull the kneecap (the patella) out to the side more, sometimes causing what is called patellofemoral syndrome—a painful condition that appears to occur more frequently in women. In men, the muscle and bone run more directly vertically, putting less lateral pull on the patella. Some studies also indicate that women's joints and muscles may tend to be more lax than men's; although this adds to greater flexibility, it may mean that female joints and muscles are not necessarily as stable.

Increased laxity and differences in limb alignment may contribute to ACL injuries among female athletes. And yet, even though physicians and coaches



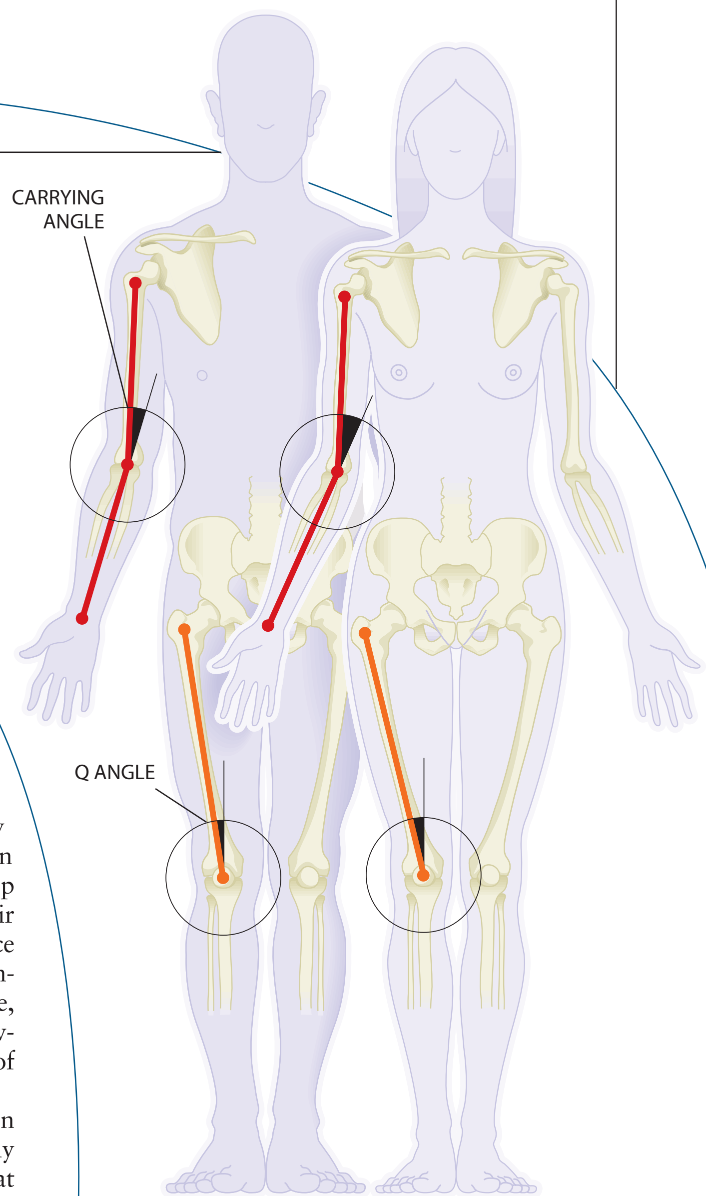


SOURCES: National Collegiate Athletic Association Participation Statistics Report, 1982–98; National Federation of State High School Associations Participation Study

LISA BURNETT

The Inside Story on Injury

The skeletons of women differ from men's most visibly in the width of the pelvis. As a result, women have a wider Q angle (a measure of bone alignment from hip to knee) and carrying angle (from upper to lower arm), which can lead, respectively, to higher rates of knee and elbow or shoulder injuries.



SAMUEL VELASCO

first recognized in the 1980s that female athletes were more prone to this injury, there is still no resolution about the cause. "It is an area of controversy," observes Joseph Bosco, an orthopedic surgeon at New York University.

Some experts place the blame squarely on laxity, musculoskeletal configuration and a few other physiological differences. They note that the bony notch the ACL passes through as it attaches to the lower leg bone may be proportionately smaller in women. Other researchers have shown that women typically favor using their quadricep muscles (at the front of the thigh) rather than their hamstrings (at the back of the thigh), an imbalance that may rip the ACL. And still others think the injury is more related to the training women receive, their skill level and their overall fitness. Most, however, agree that it is some combination of several of these factors.

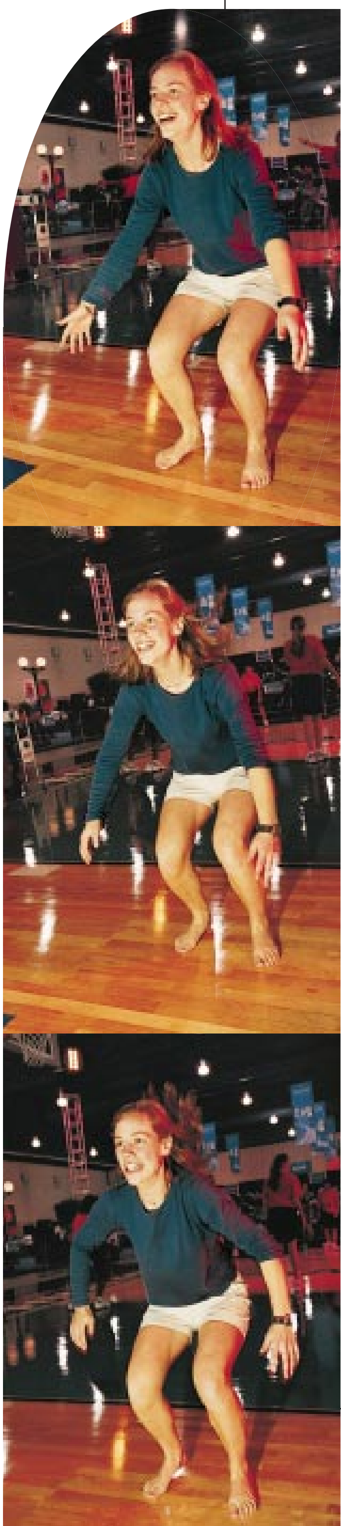
Recent studies indicating that ACL injuries can be prevented by training women to jump differently and to develop their hamstring muscles suggest that inadequate training is at least a large part of the problem. "We train and condition women in the same way that we do the men," says Wojtys, who showed in a 1999 study that women tend not to bend their knees as much as men do when they land a jump, thereby increasing the pressure of the impact on the joints. "They probably need their own training programs."

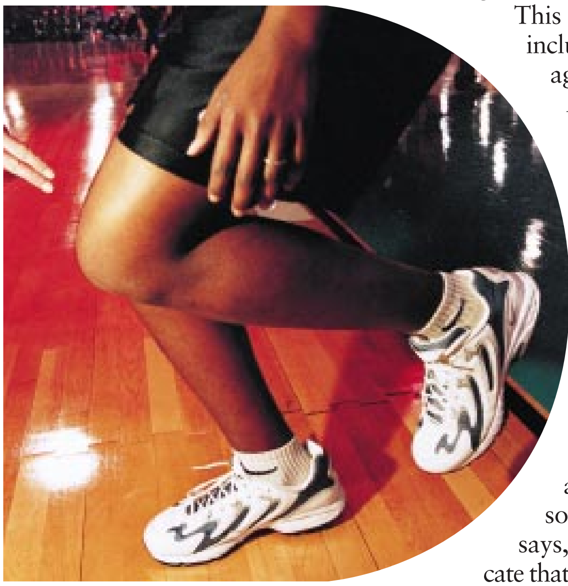
The Cincinnati Sportsmedicine and Orthopaedic Center focuses on just such an approach. In 1996 Frank R. Noyes and his colleagues there followed 11 high school girl volleyball players who went through Sportsmetrics, a grueling six-week jump-training program the researchers had created. They found that all the participants improved their hamstring strength and that all but one were able to reduce their landing forces, placing less stress on their knees as a result (and achieving the "quiet landing" Saint-Phard was looking for in Philadelphia).

The investigators went on to follow two new groups of female athletes—those who did this strength training and those who did not—as well as a group of male athletes without Sportsmetrics. In an article published last year in the *American Journal of Sports Medicine,* the authors, led by Timothy E. Hewett, reported that only two of the 366 trained female athletes (and two of the 434 male athletes) suffered serious knee injuries, whereas 10 of the 463 untrained women did. They concluded that specially trained female athletes were 1.3 to 2.4 times more likely to have a serious knee injury than the male athletes were, whereas the untrained females were 4.8 to 5.8 times more likely.

The idea that better, or perhaps more, training could have a strong effect on injury rates is supported by work with another set of women: army recruits. According to a recent study by Nicole S. Bell of the Boston University School of Public Health, female recruits were twice as likely to suffer injuries during basic combat training than men were—and two and a half times more likely to have serious injuries. The injuries were not only knee-related but included sprains and stress fractures of the foot and lower leg. Bell found that, overall, the women were not in as good shape as the men were and that a lack of fitness was associated with injury rates in both

HAPPY LANDING: In a Philadelphia gym, one woman tries to land jumps (*below*) with her knees straight forward instead of knocked to reduce the chance of ACL injury, while another (*right*) strengthens muscles around her knee.





sexes. Many girls don't participate in sports as they are growing up, typically getting started only in late junior high school or beyond, Noyes says. "The boys have been running around playing tanks and guns, and the girls have been playing house," he says. "That goes along with the theory that girls are less fit."

Despite the growing consensus about the benefits of jump training, the approach is in limited use. Saint-Phard and her colleagues have led the injury prevention workshop they held in Philadelphia in schools around New York City. But they reach a very small group of young women and coaches. The challenge, Noyes and others note, is getting to the wider community of coaches, parents and trainers. "We need training programs nationwide," Noyes insists. He says that although some coaches are happy to see him, the rest consider knee-strength training a six-week regimen that just holds up team practice.

Noyes is also working to redress another sports medicine imbalance. Historically, men have been more likely than women to have knee surgery. Noyes believes that there are two reasons. First, knee surgery used to be a difficult procedure with often poor outcomes, so it was limited to athletes who really "needed" it—in other words, professional male athletes. Second, there has been a perception among physicians that women would not fare as well during the often painful surgery and recovery. So Noyes and his colleagues decided to examine the responses of both men and women to ACL surgery. They determined that although women took slightly longer to heal, both sexes fared equally well in the long run.

Noyes's work on surgery outcomes and the growing consensus about the importance of neuromuscular control appear to have shifted some attention away from another area of ACL injury investigation: hormonal influences. Researchers have found that the ACL has estrogen and progesterone receptors—target sites that respond to those two hormones. In studies in animals and in vitro, they have discovered that the presence of estrogen decreases the synthesis of collagen fibers, the building blocks of ligaments. It also increases the levels of another hormone, relaxin, which in turn adds to the disorganization of collagen fibers. This change in the ligaments makes the ACL more flexible and, according to the hypothesis, more vulnerable to injury.

This view seems supported by some studies, including one by Wojtys published two years ago in the *American Journal of Sports Medicine*. He and his team questioned 40 women with ACL injuries; the majority of the tears occurred during ovulation, when estrogen levels were highest. Other studies show some increased muscle laxity in ovulating women, but nothing dramatic.

Wojtys's study has been contested as suspect because it was based on such a small sample size, because the women's ages were so variable and because the researchers were relying on the athletes' recollections. And Wojtys himself agrees that nothing is definite. "It is not something you can hang your hat on," he says, noting, however, that other studies indicate that women on birth-control pills have a much lower rate of injury—presumably because they don't ovulate and their estrogen levels are lower. "It is indirect evidence; none of it is confirmatory. But to ignore it and not investigate doesn't make any sense," he says. Wojtys, whose interest in women's sports medicine was catalyzed by his two daughters' love of sports, says that he is not averse to being proved wrong and adds that, in fact, he hopes he is.

"Estrogen probably has some role," notes Jo A. Hannafin, orthopedic director at the Women's Sports Medicine Center. But, she says, no one is applying the studies' findings to the court—limiting, say, what time of month a player should or should not play. The hormonal result "just reinforces old stereotypes," Bosco adds. "It takes weeks and weeks for the effects [of estrogen] to be seen, so it doesn't make sense. We still strongly encourage women to participate in athletics over the whole month."

TREATING THE TRIAD

Estrogen's role in the other major health threat to female athletes is not at all controversial. Exercise or poor eating, or both, can cause an athlete's body to develop an energy deficit, become stressed and lose essential nutrients. Any or all of these changes can cause levels of follicular-stimulating and luteinizing hormones to fall and ovulation to therefore

JAMES LEYNSE *SABA*

cease. Absent their menstrual cycles, young athletes do not have the requisite estrogen at precisely the time they need the hormone the most to help retain calcium and lay down bone. By the age of 17, nearly all a young woman's bone has been established, explains Melinda M. Manore, a professor of nutrition at Arizona State University. If an athlete's level of estrogen remains low, she can start to lose bone mass at a rapid rate, which can lead to stress fractures and, if the process is not curbed, premature osteoporosis.

The phrase "female athlete triad" was coined in 1992 by participants at an American College of Sports Medicine meeting. Since then, anecdotal reports have indicated that the occurrence of the triad is on the rise. "I think young women are more and more aware of their body size," Manore says. Furthermore, female athletes are especially vulnerable. Eating disorders—such as obsessive dieting, calorie restriction or aversion to fat (all labeled disordered eating), as well as anorexia and bulimia (the so-called classic eating disorders)—are disproportionately high in girls and women who participate regularly in sports.

Averaged across various sports, some 30 percent of these individuals have an eating problem, as opposed to 10 to 15 percent of the general population—although no one knows for sure, because no large-scale studies on prevalence have been conducted in the U.S. The proportion may be as high as 70 percent in some sports. "High achievers, perfectionists, goal setters, people who are compulsive and determined—those are the things that characterize our best athletes," says Margot Putukian, a team physician at Pennsylvania State University. Those are also the very qualities that often lead people into problem eating.

And athletic culture—particularly for swimmers, runners, skiers, rowers and gymnasts—only continues to reinforce these behaviors and expectations. Many coaches encourage their athletes to lose weight so they can be faster or have less mass to move through acrobatic maneuvers. According to a recent study, female gymnasts weigh 20 pounds less than those in the 1970s did. And many female athletes at all levels see losing their period as a badge of honor. "They don't see it as a negative," Putukian explains. "They see it as something that happens when you get in shape, a sign that you are training adequately." What they also don't see is what is happening to their bones—until they develop stress fractures. "They fly through their adolescent years with no knowledge of why being too thin is dangerous," Saint-Phard says.

Treating the triad is challenging, and, as Putukian notes, "there is not a lot of great data to tell us what is the best thing." Researchers now recognize that female athletes experiencing these problems need the combined talents of a physician, a nutritionist and, if they have bulimia or anorexia, a psychologist—a multidisciplinary team that most schools and colleges lack. "When you have a kid who has an eating disorder, it is very frustrating," Putukian says. "It is reversible if you catch it early on, irreversible if you don't." She tells her athletes—who are all questioned about their menses and their eating habits during their initial physical—that if they haven't had their period for three months, they are in danger. Putukian tries to get them on a birth-control pill and works with them to change their eating habits if they have a problem. But although the pill restores some hormonal activity, it does not provide the requisite levels for normal bone development. And hormone replacement therapy, which is used by some physicians, has not been extensively tested in young women.

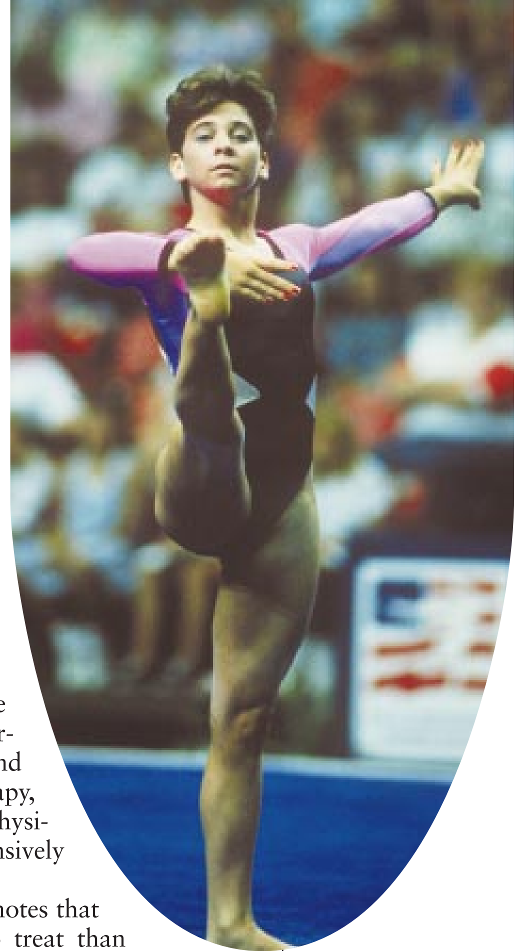
Nevertheless, Putukian notes that athletes may be easier to treat than women in the general population because there is an incentive: competition. "It is an incredible tool," she says. "You can help kids come back." Putukian has refused to let several athletes compete until they got their weight up to healthy levels; their desire to participate drove them to improve their eating habits.

Putukian, Manore and others would like to see young women better educated about the consequences of excessive dieting and amenorrhea. They admit that little can be done about the cultural pressures facing young women—the unrealistic icons of emaciated beauty that destroy many self-images. But they believe that if girls understand that they may be jeopardizing their freedom to take a simple jog in their 30s without fracturing their osteoporotic hips or leg bones, they will change their behavior. The investigators hope that athletes will focus on how they feel and how they perform, rather than on how much they weigh. But as with the jump-training program to prevent ACL injuries, there remains a great divide between the medical community's recommendations and the reality of the track or court or gymnasium. Only when those are fully integrated will Title IX have truly fulfilled its promise.

MARGUERITE HOLLOWAY is a contributing editor at *Scientific American.*

FURTHER INFORMATION

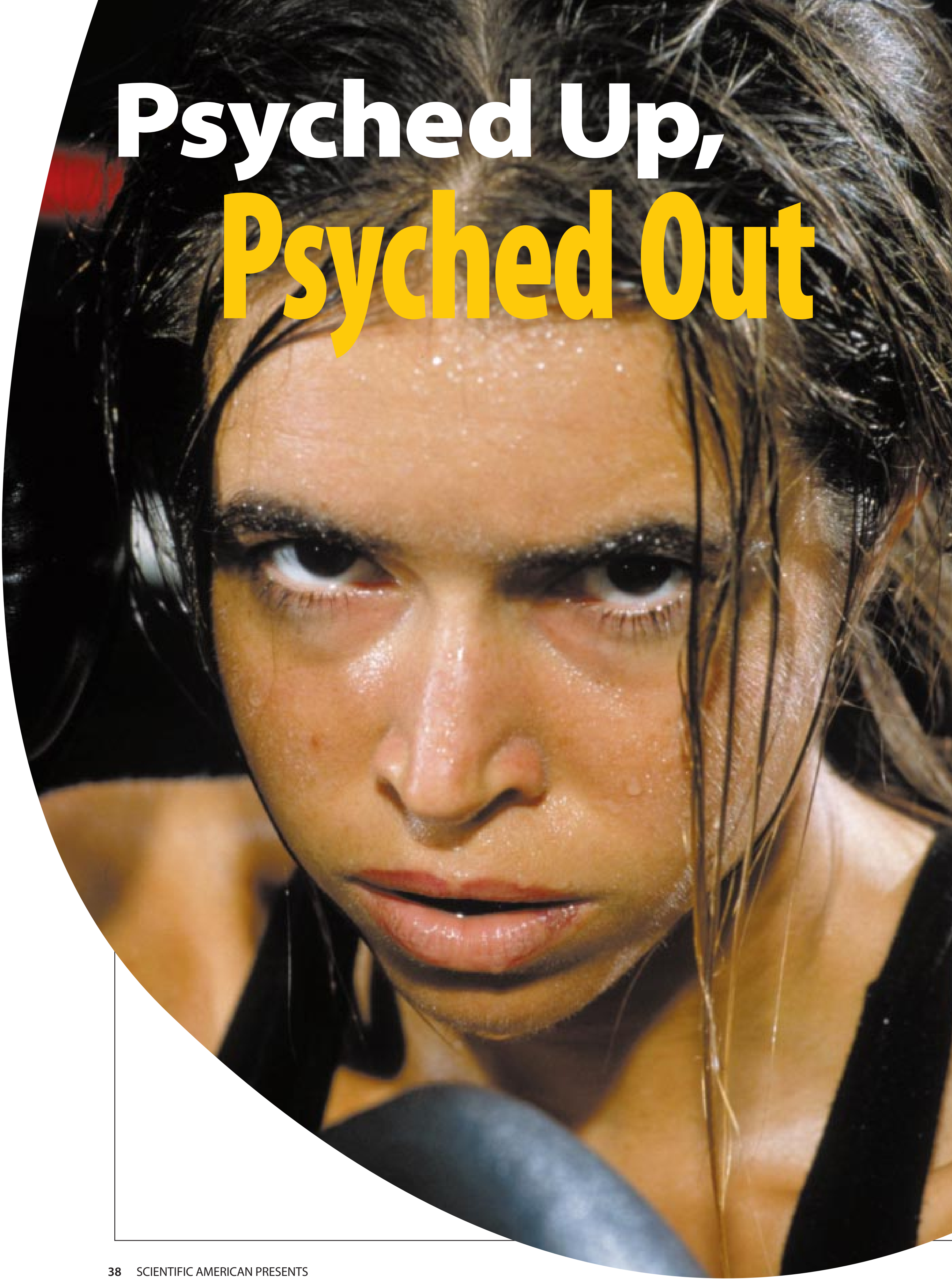
A variety of entries on women's injuries and sports medicine can be found in *The International Encyclopedia of Women and Sports,* edited by Karen Christensen et al. (Macmillan, 2000).

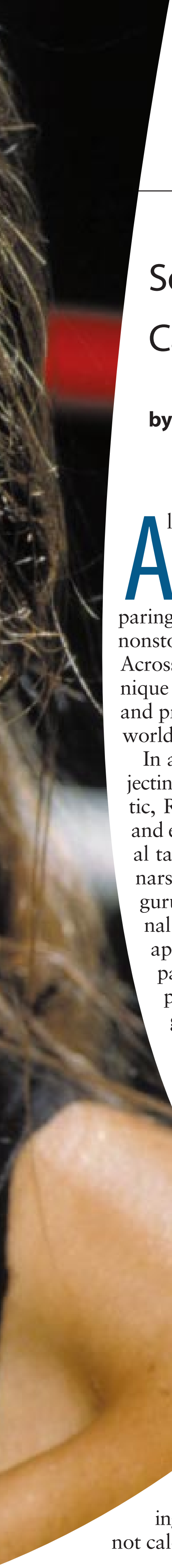


CROSSING THE LINE: U.S. gymnast Christy Henrich weighed 47 pounds when she died in 1994 at age 22. Many female athletes are urged, or urge themselves, to lose weight in an effort to hone their performance. This pressure can lead to the female athlete triad—with tragic consequences.

MIKE SCULLY *Allsport*

Psyched Up, Psyched Out





MIKE POWELL *Allsport*

Some athletes swear by it. Others laugh at it. Can science determine if sports psychology works?

by Michael Shermer

Although I was trained as an experimental psychologist, I didn't become interested in how psychology could enhance athletic performance until 1981. That's when I began preparing to compete in the first annual 3,000-mile, nonstop transcontinental bicycle race, the Race Across America. I thought I had better try any technique I could find to prepare my mind for the pain and pressures of what *Outside* magazine calls "the world's toughest race."

In addition to riding 500 miles a week and subjecting my body to such "treatments" as chiropractic, Rolfing, mud baths, megavitamins, iridology and electrical stimulation, I listened to motivational tapes. I meditated. I chanted. I attended seminars by Jack Schwarz, an Oregon-based healing guru who taught us "voluntary controls of internal states." I contacted Gina Kuras, a hypnotherapist who taught me self-hypnosis to control pain, overcome motivational lows, maintain psychological highs and stay focused. I got so good at going deep into a hypnotic trance that when ABC's *Wide World of Sports* came to my home to film a session, Gina could not immediately bring me back, causing her to fear that I had somehow harmed myself.

Did all this New Age fiddle-faddle work? I really can't say it did, as a scientist or a cyclist. Still, I'm glad I had these crutches during my 10 days of leg-burning, lung-searing riding. As Mark Victor Hansen, an apostle of the motivation movement and coauthor of the Chicken Soup for the Soul book series, would chant, "This stuff works when you work it." On one level Hansen is right. As with fad diets, it matters less which one you are on and more that you are doing something—anything—about your eating habits. Diets are really a form of behavioral, not caloric, modification. The point is to be vigilant and focused, thinking about the problem and trying different solutions.

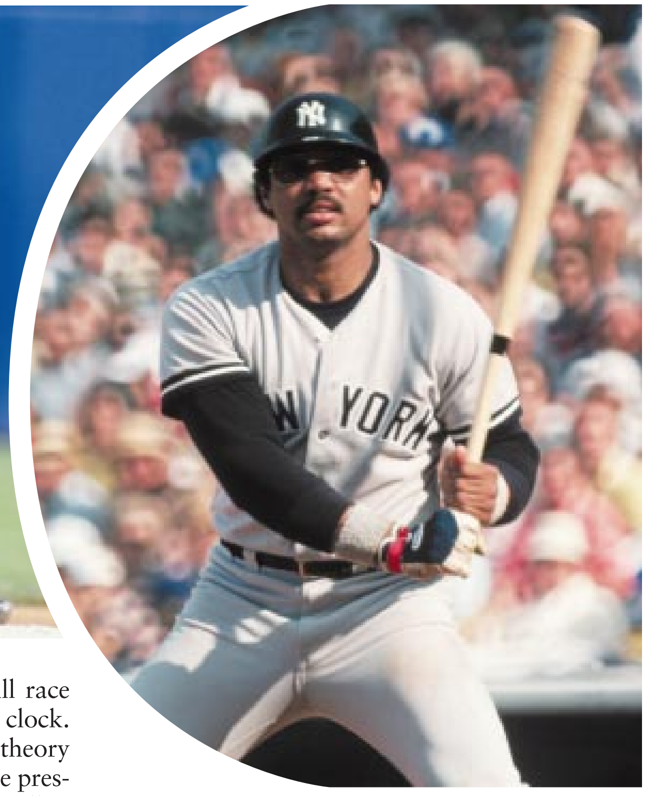
But the deeper and more important question is: Can we say scientifically that sports psychology techniques work? Obtaining an answer is complicated, because so many of these self-help methods are based on anecdotal evidence. As my social science colleague, Frank Sulloway, likes to point out: "Anecdotes do not make a science. Ten anecdotes are no better than one, and 100 anecdotes are no better than 10."

Without controlled comparison groups, there is no way to know if an effect that was observed was the result of chance or the technique. Did you win the race because of the meditation or because you had a deep sleep, a good meal, new equipment or made progress in your training? Even if a dozen athletes who applied a certain procedure before an event performed better, without a control group there is no way to know what really led to the improvement. And when we say that an athlete performed "better"—better than what? Better than ever? Better than yesterday? Better than average? Conducting a scientific evaluation of the effectiveness of psychological aids on athletic performance is a messy business.

THE DESIRE TO WIN

Sports psychology began in the 1890s, when Indiana University psychologist Norman Triplett, an avid cyclist, performed a series of studies to determine why cyclists ride faster in groups than when they are alone. Triplett discovered that the presence of others, whether competitors or spectators, motivates athletes to greater performance. As sports have become professionalized, the field has paralleled the trends in general psychology, applying behavioral models (how rewards and punishment shape performance), psychophysiological models (the relation between heart rate and brain-wave activity and performance) and cognitive-behavioral models (the connection between self-confidence and anxiety with performance).

The goal, of course, is to understand, predict, and enhance the thinking and behavior of athletes. Studies show that a cyclist will ride faster when another cyclist is riding alongside or even behind than when the



EMOTIONAL PLAY: The rash of wild throws this summer by one-time Gold Glover Chuck Knoblauch (*left*) had psychologists guessing about stress related to his ailing father. Some players thrive on competitive stress; although Reggie Jackson (*right*) hit his share of home runs during the regular season, "Mr. October" unleashed strings of them in high-pressure postseason games.

AL BELLO *Allsport (Knoblauch)*; NEAL PRESTON *Corbis (Jackson)*

cyclist is alone. And the average cyclist will race faster against a competitor than against the clock. Why? One reason is "social facilitation," a theory in which individual behavior is shaped by the presence and motivation of a group (think mass rallies and rock concerts). But what is actually going on inside the athlete's brain and body? Well, competition provides the promise of positive (and the threat of negative) reinforcement, stimulates an increase in physiological activity and arousal, and locks the athlete into a self-generating feedback loop between performance expectations and outcomes. This constant feedback causes competitors to push one another to the limits of their physical capabilities.

MR. CLUTCH VS. MR. CHOKE

Yet as in all psychological situations, outside variables alter the theoretical effect. Competition and crowds can increase an athlete's anxiety, causing him or her to crumble under fans' expectations. Basketballs that swish in during practice clank off the rim in the game; aces on the practice court turn into double faults at center court. But the same stimulation can accelerate the heart rate and adrenaline of another athlete, accentuating the drive to win. Some athletes are at ease under pressure: Reggie Jackson as "Mr. October," Jerry West as "Mr. Clutch." Others falter: Bill Buckner's infamous through-the-legs error at first base that cost the Boston Red Sox the crucial Game 6 of the 1986 World Series; Scott Norwood's muffed field goal in the closing seconds of the Buffalo Bills's best opportunity for a Super Bowl ring thus far.

Sports psychologists offer several explanations for this variance. It comes down to personality: some individuals are just better at risk taking, competitiveness, self-confidence, expectation for success and the ability to regulate stress. And some have an easier time hewing to the basic winning habits of professional athletes: practice a lot, come prepared with a contingency plan for changes in the competition, stay focused on the event and block out distracting stimuli, follow one's own plan and not those of the competitor, don't get flustered by unexpected events, learn from mistakes, and never give up.

The complexity of the task and the nature of the competitive situation also affect each athlete's ability to rise or fall in the heat of competition. The 100,000 screaming fans lining the final kilometers of a crippling climb up the French Alps in the Tour de France might catapult a cyclist onto the winner's podium but could cause a golfer to knock his five-foot putt into the sand trap or a gymnast to do a face plant into the mat. Context counts.

So does attitude. Psyching out an opponent is another mental game that can affect an athlete's performance. It is extremely complicated to test; suffice it to say that it can happen. And place a vote for Muhammad Ali as the greatest practitioner in history. Ali imposed his own psychological edge over rivals better than any athlete in the 20th century, earning him the title of "The Greatest."

HOME-COURT ADVANTAGE

Physiological arousal also tampers with an athlete's performance; too little or too much are both deleterious. And, again, each athlete varies in how much arousal is ideal for peak performance. Russian sports psychologist Yuri Hanin, for example, describes "zones of optimal functioning," in which athlete A does best when minimally aroused, athlete B performs best at a medium level of arousal, and athlete C responds to a high level of arousal.

Arousal of an entire team may explain, or debunk, the so-called home-court advantage. We all "know" that competitors have an advantage when playing at home. Teams strive all season to finish with the best record in order to get it. Research shows that on average and in the long run, football and baseball teams do slightly better at their own stadiums than at their competitors', and basketball and hockey teams do significantly better at home than away (the smaller arenas presumably enhance social facilitation). But the advantage may hold only for regular-season games. The influence seems to wane during preseason and postseason play. For example, a study of World Series contests from 1924 to 1982 showed that in series that went five games or more, the home team won 60 percent of the first two games but only 40 percent of the remaining games. Interestingly, in the 26 series that went to a nail-biting seventh game, the home team came away empty-handed 62 percent of the time.

Since 1983, however, the trend has shifted somewhat. In analyzing the data, I found that between 1983 and 1999 the home team won only 54 percent of the first two games but went on to win 80 percent of the deciding seventh games. Perhaps teams, like individual players, vary in their zones of optimal functioning. It is also possible that in some instances overzealous fans become fanatics (whence the term comes) in the final stretch, driving their teams into such an intense state of unrealistic expectations that it stymies performance. Or helps it.

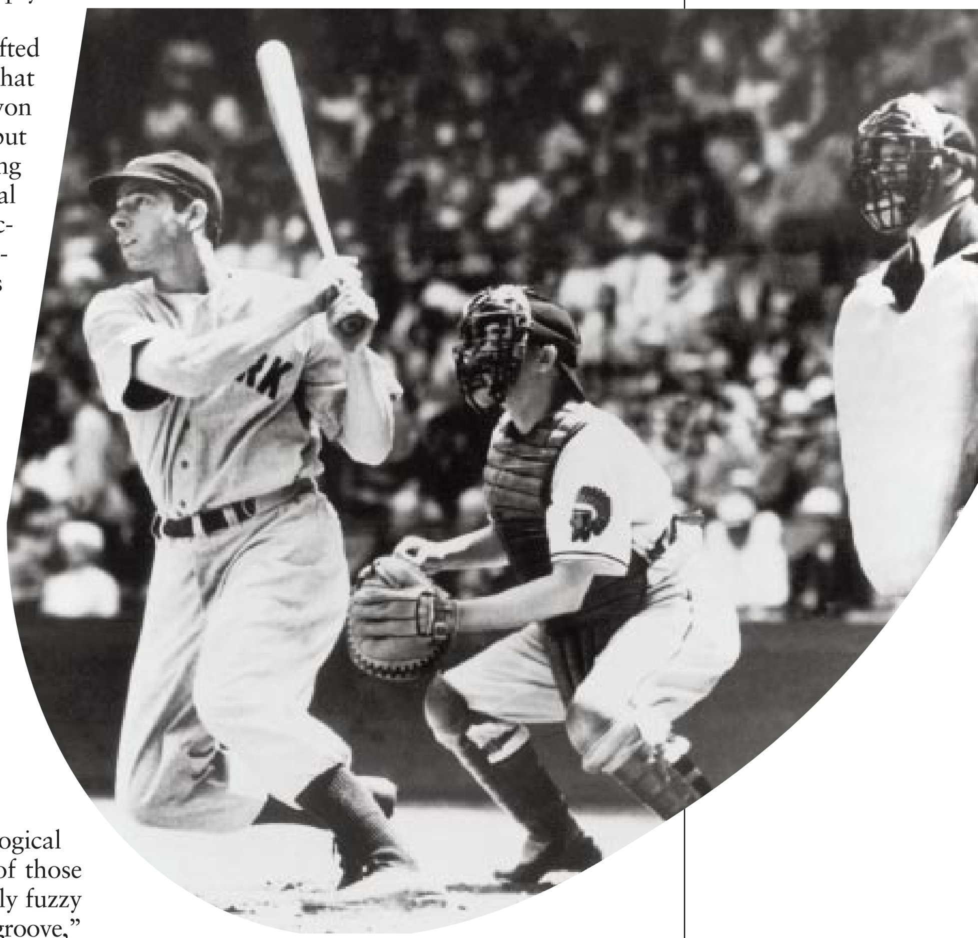
What the ambiguous outcome of this scientific analysis tells us is that human variation confounds the predictive validity of most sports psychology models. As all evolutionary biologists know—and experimental psychologists tend to forget—variation within a species is the norm, not the exception. And in few species is variation more pronounced in so many variables than in humans. Throw into this mix the complications of social and cultural sports factors, and the models break down.

THE LIE OF BEING "IN THE GROOVE"

Science has also shed light on the psychological notion of peak performance. It is one of those fuzzy concepts athletes talk about in equally fuzzy expressions, such as being "in sync," "in the groove," "in the zone," "letting go"and "playing in a trance." Psychologists describe it with such adjectives as "relaxed," "focused," "energized," "absorbed" and "controlled." But these are just ways to describe some poorly understood connection between mental states and physical performance. Something—we don't know what—is going on inside the brain and body that allows the athlete, every once in a while, to put it all together. The golf ball drops into the cup instead of skirting the edge. The hit baseball always falls where they ain't. The basketballs swish in one after another. When you're hot, you're hot.

But maybe not. Streaks in sports can be tested by statisticians who specialize in probabilities. Intuitively we believe that hot streaks are real, and everyone from casino operators to sports bookies counts on us to act on this belief. But in a fascinating 1985 study of "hot hands" in basketball, Stanford University behavioral scientist Amos Tversky and his colleagues analyzed every shot taken by the Philadelphia 76ers for an entire season. They discovered that the probability of a player hitting a second shot did not increase following an initial successful basket beyond what would be expected by chance and the average shooting percentage of the player.

In fact, what they found is so counterintuitive that it is jarring: the number of streaks (successful baskets in sequence) did not exceed the predictions of a statistical coin-flip model. If you conduct a coin-flip experiment and record heads or tails, you will shortly encounter streaks. On average and in the long run, you will flip five heads or tails in a row once in every 32 sequences of five tosses. Because Tversky was dealing with professional basketball players, however, adjustments in the formula were made to account for ability. If a player's shooting percentage is 60 percent, for example, chance dictates that he will sink six baskets in a row once in every 20 sequences of six shots attempted. When



HOT BAT: Few "streaks" actually defy statistical chance, but scientists say Joe DiMaggio's 56-game hitting streak "should never have happened at all."

AFP/CORBIS

average shooting percentage was controlled for, Tversky found that there were no shooting sequences beyond what was indicated by chance. Players might feel "hot" or "in flow" when they have games that fall into the high range of chance, but science shows that nothing happens beyond what probability says should happen.

There is one exception to this principle: occasionally, all the human variables can come together in a unique fashion that leads to a performance so rare that it is not matched for decades, or ever. Bob Beamon's unbelievable long jump of 29 feet, 2.5 inches, at the 1968 Olympic Games in Mexico City, surpassed the old mark by a remarkable 21.75 inches and was not bettered for more than two decades. Even more remarkable was Joe DiMaggio's 56-game hitting streak. It was a feat so many standard deviations away from the mean that, in the words of physicist Ed Purcell and paleontologist Stephen Jay Gould, who calculated its probability, it "should not have happened at all." It ranks as perhaps the greatest achievement in modern sports. Individual greatness can defy science and throws a new wrench into the tightly coiled machinery of psychological theory.

DOES VISUALIZATION WORK?

Like most social scientists, sports psychologists are much better at understanding behavior than at predicting or controlling it. It is one thing to model all the variables that cause some athletes to triumph and others to flounder. It is harder to predict which athletes will step up to the winner's podium and virtually impossible to turn Andy Airball into Michael Jordan. Here we enter the murky world of performance enhancement and sports counseling—the art of sports psychology.

One of the most common and effective techniques is imagery training, or visualization, wherein an athlete envisions himself executing the physical sequences of the sport. We have all seen Olympic downhill skiers minutes before their run standing in place with their eyes closed, their bodies gyrating through the course. Gymnasts and ice skaters are also big on visualization. Even cyclists practice it: Lance Armstrong attributed his extraordinary 1999 Tour de France victory in part to the fact that he rode every stage of the race ahead of time, so that during the race itself he could imagine what was coming and execute his preplanned attacks. Countless experiments show that groups that receive physical and imagery training on a novel task do better than groups that receive only physical training.

Nevertheless, failures of imagery-trained athletes are legion. We hear about Lance Armstrong but not about all those other cyclists who mentally rode the Tour ahead of time and finished in the middle of the pack. We don't hear about the visualizing downhill skiers who crash or the imagining gymnasts who flop. Did riding the course ahead of time give Armstrong a psychological edge or just a better race

HOW TO AVOID CHOKING

[redacted]

Even Michael Jordan makes mistakes. No matter how good an athlete is, "choking" is inevitable. The difference is that the pros have trained both mentally and physically to reduce its likelihood and to recover from it. Sports psychologists Robin Vealey of Miami University of Ohio and Daniel Gould of the University of North Carolina at Greensboro offer some tips:

Focus. Choking often occurs when your thoughts are on the past or the future. Focus on the present, and be conscious of your emotional and physical reactions to a stressful situation.

Practice. Practice in stressful situations in order to get used to physical and mental tension. Mental and muscle memory interact, and you can train them together to create conditioned responses to tense circumstances.

Relax. Stress makes your mind hurry and your muscles tense up. Use breathing techniques to relax, and consciously loosen tight muscle groups.

Talk to yourself. Self-talk can calm, remotivate and remind you of your best technique. Use a "mantra with meaning"—for example, a tennis player can remind herself to have "quick feet" so she is moving and ready. And don't obsess over a mistake; instead replace a negative mental image of yourself with a positive one to bring you back into the game.

Know yourself and your environment. Perceived pressure from teammates, coaches and yourself can cause you to freeze up. Remember: it's just a game. Pick the challenges and competitions you think you can handle. *—Naomi Lubick*

JED JACOBSOHN *Allsport*

AT HOME: Basketball and hockey teams win more games inside their home arenas than football and baseball teams do on their own turf.

plan? Visualization may be little more than good, utilitarian planning.

Even the most enthusiastic supporters of imagery training caution that numerous variables can interfere with the technique's benefits. University of North Carolina sports psychologists Daniel Gould and Nicole Damarjian caution that "imagery is like any physical skill. It requires systematic practice to develop and refine. Individual athletes will differ in their ability to image. Imagery is not a magical cure for performance woes."

FLOODED WITH FLAPDOODLE

What Gould and Damarjian seem to be saying is that this stuff works when you work it. But what does that mean? To determine if a psychological technique "works," we might evaluate it by two standards: whether it works for an individual and whether it works for everyone. For the athlete who wins the gold medal, whatever he or she did "worked." It does not matter what scientists think of the techniques that were used, because there was a positive outcome. That satisfies the first criterion.

But will a given technique used by that winning athlete work for all athletes? Here we face a problem that hangs like an albatross around the neck of clinical psychology. There is very little experimental evidence to suggest that it will. I do not go as far as psychiatrist Thomas Szasz in his claim that mental illnesses are all socially constructed. Nor do I accept all of clinical psychologist Tana Dineen's argument that the "psychology industry" is "manufacturing victims" in order to feed its growing economic juggernaut. But these two extremists have injected a badly needed dose of skepticism into a field flooded with flapdoodle. Both the practitioners and participants in sports psychology would be well advised to step back and ask themselves whether it is good enough if an individual believes a technique helps and, if not, how science can prove it has value.

So did all the psychological exercises I tried "work" for me in the Race Across America? It is impossible to say, because I was a subject pool of one and there were no controls. When I wanted them to work, it seemed like they did, and maybe that's good enough. Yet I cannot help but wonder if a few more hours in the training saddle every day might have made a bigger difference. Sports can be psychological, but they are first and foremost physical. Although body and mind are integrated, I would caution not to put mind above body.

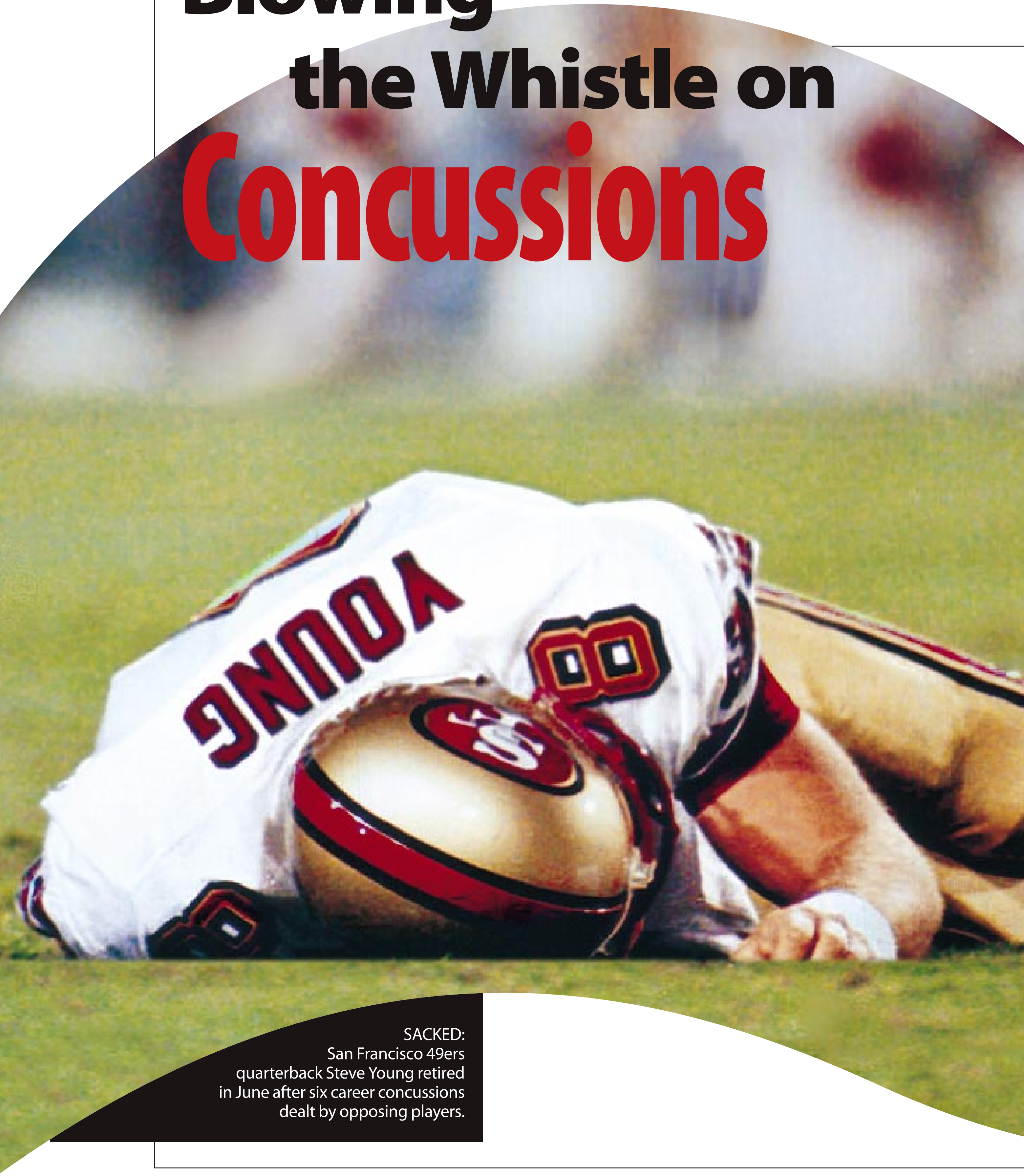
MICHAEL SHERMER is an experimental psychologist, publisher of *Skeptic* magazine (www.skeptic.com) and author of *Race Across America: The Agonies and Glories of the World's Longest and Cruelest Bicycle Race.*

FURTHER INFORMATION

SPORT PSYCHOLOGY: FROM THEORY TO PRACTICE. M. H. Anshel. Allyn & Bacon, 1997.

CASE STUDIES IN SPORT PSYCHOLOGY. B. Rotella et al. Jones and Bartlett, 1998.

Blowing the Whistle on Concussions



SACKED: San Francisco 49ers quarterback Steve Young retired in June after six career concussions dealt by opposing players.

Raps to the head can debilitate or even kill athletes. Yet concussions are often misdiagnosed and mistreated

by Polly Shulman

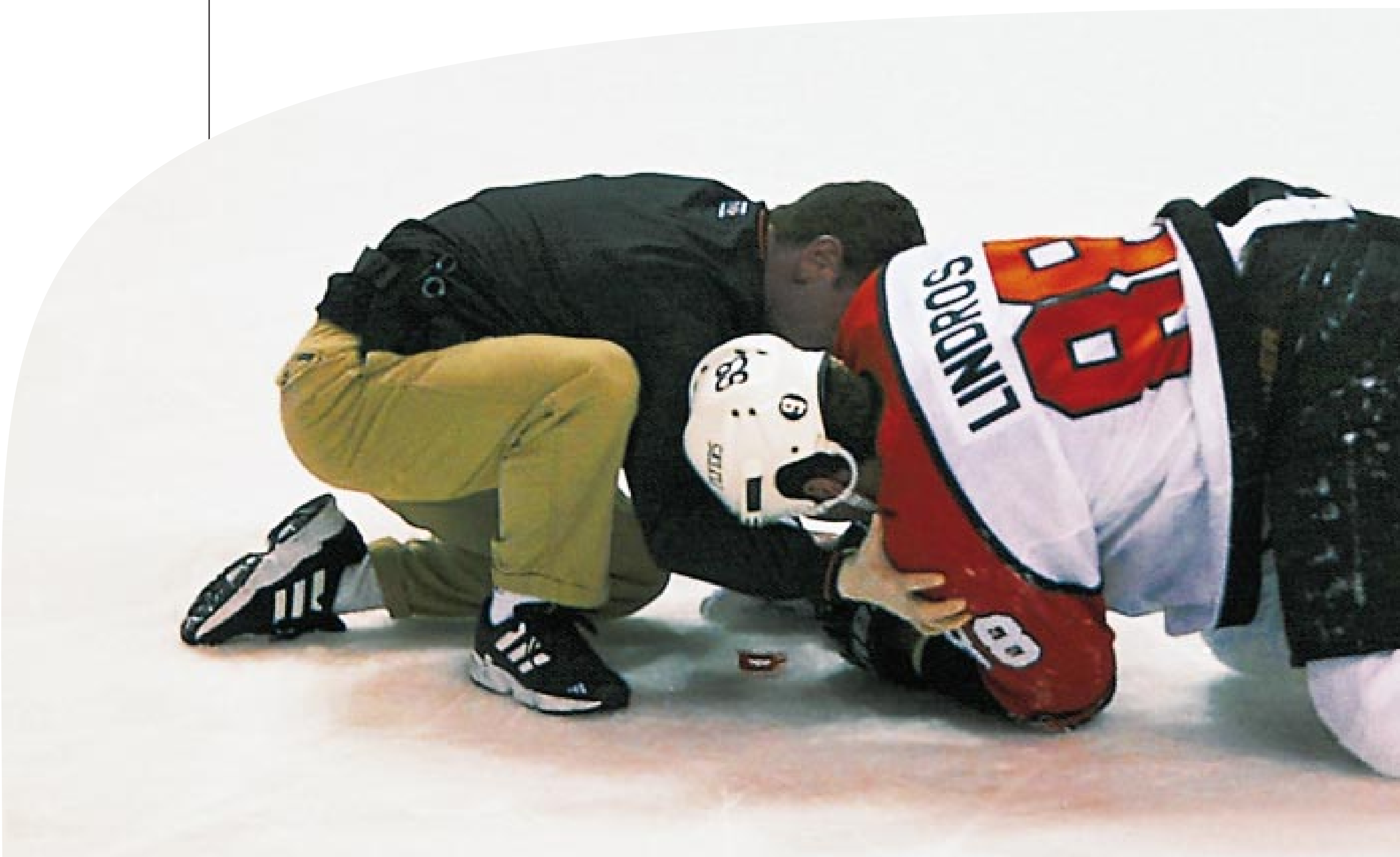
SCOTT TROYANOS *AP Photo*

Immediately after being elbowed in the jaw by Boston Bruin Hal Gill during a March 4 hockey game, Eric Lindros's world went yellow. The star center of the Philadelphia Flyers fell to the ice. He was helped into the locker room by the team's trainer, then vomited. He complained of a bad headache and strangely colored vision. Team doctors gave him heat packs and ibuprofen and then put him back in the lineup for another four games. "I wanted to keep playing," despite the telltale signs of a concussion, Lindros told reporters. "That's the mentality of a player—'Everything's going to be fine, it's going to go away,' and you just keep on playing." He added, "I knew that things were not good, and I tried to convey that through my symptoms. But I was not going to pull myself out of the game. I wanted the team to pull me out. I was hoping as the week went on that they would do that."

It was nine days before team doctors sent Lindros to a headache specialist, who referred him to James P. Kelly, an expert in sports-related concussions who is based at Northwestern University Medical School. Kelly diagnosed Lindros with a moderate concussion. Playing in subsequent games would put the athlete at serious risk: a second concussive hit sustained before the first one had healed could cause permanent brain damage or even death.

Lindros did not recover well. He sat out for 10 weeks, returning only for the crucial last two games of the Eastern Conference finals in May. He had played just eight minutes of Game 7 when he was elbowed again, this time by New Jersey Devil Scott Stevens. Lindros went down hard. It was his fourth concussion of the season and his sixth in two years. In the following days doctors said that Lindros should hang up his skates, and the sports media conjectured widely about the 27-year-old's premature retirement. And yet in July rumors arose that he might be traded, with several teams said to be interested.

Lindros is a perfect example of the dangers that sports-related concussions pose. According to the Centers for Disease Control and Prevention, 20 percent of the brain injuries that occur yearly in the U.S. can be attributed to athletics. That's more than 300,000 concussions. High school, college and amateur athletes receive most of these injuries, because there are so many more of these players than there are pros. "This is a major public health issue that's been given short shrift," says Michael W. Collins of the Henry Ford Hospital in Detroit. "It's underrecognized, underdiagnosed and misdiagnosed. It's happening with alarming frequency at the high school, college and professional levels."



COLD AS ICE: Relations between Eric Lindros and Philadelphia Flyers management chilled this spring after he accused the team doctors of mistreating his many concussions.

A single blow to the head can cause a whole range of symptoms, from problems with balance and coordination to impaired decision making, failing memory and personality changes. Unless the injury is severe, patients generally recover with time. But most athletes return to games or practices far too soon. A second blow before a concussion is fully healed has a far greater chance of imposing more serious, longer-lasting harm. There is also the risk of death from "second impact syndrome," a rare condition in which the brain swells fatally. Furthermore, "there's growing evidence that not only are you more likely to have another concussion if you've had one, but the problems accumulate," Kelly says.

Although the professional-athlete cases get the media attention, the thousands of kids playing youth hockey, football and soccer, the thousands of high school and college athletes, and the thousands of weekend jocks are in even greater danger, because it is far less probable that they, their coaches or their parents will recognize the symptoms of concussion. Scientists are trying to develop guidelines to help amateurs as well as pros recognize the signs and severities of concussions, but it is an inexact science. And there are currently no treatments that make concussions heal faster.

Lindros's sad string of concussions threatened not only his health but his image. His dissatisfaction with the way the team's staff handled his ongoing injury has caused bad blood with team general manager Bob Clarke, who stripped Lindros of his captaincy. "When a guy like Lindros comes out and criticizes the doctors and trainers, he's thinking of himself and not the team," Clarke said at the time. If concussions end the hockey star's career, he will be the second Lindros knocked out by brain injury. His younger brother, Brett, had to retire from the National Hockey League at the ripe old age of 20, after suffering three concussions with the New York Islanders and an unknown number before joining the league.

The list of elite athletes whose careers have been curtailed by brain injury is long: hockey players such as Pat LaFontaine, who retired from the New York Rangers, Paul Kariya of the Anaheim Mighty Ducks and James Patrick of the Buffalo Sabres; and football players including New York Giants linebacker Harry Carson, New York Jets receiver Al Toon, Dallas Cowboys quarterback Roger Staubach and San Francisco 49ers star quarterback Steve Young, who announced in June that he would retire early, having sustained six concussions.

HARD TO DIAGNOSE

And yet "for every Steve Young or Eric Lindros, every Muhammad Ali or Merrill Hoge, there are clearly thousands of high school kids who have had some of the same problems," neuropsychologist Collins says. Part of the trouble in diagnosing concussion is that the symptoms can be very subtle.

EZRA SHAW *Allsport*

People might dismiss a headache or altered vision as signs of stress or fatigue. "People joke, 'I got my bell rung,' but getting your bell rung means there's been some neurological change in the brain," Collins explains. People commonly think that concussion results from a knockout blow, but most concussions don't involve loss of consciousness. The primary symptoms that often go unrecognized include balance trouble, headaches, dizziness, subtle personality change and cognitive problems. Sometimes injured athletes will have difficulty calling up old memories or forming new ones.

Complicating the subjective recognition of symptoms is the athlete's desire to underemphasize injury. Young athletes are taught to "play through the pain." Few players want to sit out a stretch of important games, much less an entire season. One of the hardest challenges, Kelly says, "is getting the athletes to honestly report their symptoms and pull in the reins on themselves a bit. As much as it's admirable that the athletes are serious about getting back at it, they have to understand that these problems are very serious."

Collins agrees. Brain injuries demand more caution than orthopedic injuries do, he says; because there are no pain receptors in the brain, an individual doesn't experience direct pain with a concussion. This adds to the confusion when trying to judge symptoms. Doctors maintain that to be safe, athletes who are symptomatic following a blow to the head should be kept off the playing field and return only after the symptoms have disappeared. For more severe concussions, players should be free of symptoms for up to two weeks before resuming play [*see box on page 50*].

Because concussions can be hard to recognize for nonneurologists (including amateur coaches and trainers) and because multiple injuries are so dangerous, Collins and his colleague Mark R. Lovell of Henry Ford Hospital have devised a system of neuropsychological testing. In their scheme, each team member spends half an hour with a doctor at the beginning of the season and takes tests that measure various brain functions—repeating numbers backward, putting pegs in a pegboard, recalling words heard several minutes earlier, and so on. If they are subsequently injured, they take the tests again. "We determine when their scores are back to preinjury levels before allowing them to return to play," Lovell says. It's important to have the baseline for comparison, he emphasizes, because everyone starts out with different abilities.

Few school-level coaches are experienced at administering neuropsychological tests, however, so Lovell and Collins have developed a computerized version of the exam, which resembles a computer game. They are testing the software in schools across the country and envision placing it in the offices of pediatricians and primary care physicians. "It's like giving the brain a physical," Collins says. "If you give the rest of the body a physical, why not the brain, which is the most important organ we have?"

WHAT EXACTLY IS A CONCUSSION?

There is great misconception among the public about what a concussion actually is. It is not a bruise to the brain. It is a harsh chemical imbalance within the gray matter. A brain inside a skull is like a person riding inside a car with no seat belt, explains David A. Hovda, a neuroscientist at the University of California at Los Angeles School of Medicine. If the skull halts or spins suddenly as a result of a collision, abrupt stop or whiplash motion, the unrestrained brain mass will slam up against the inside of the skull. The brain tissue is not physically damaged, except in the worst cases. But a devastating cascade of chemical reactions is unleashed.

The slam causes all the brain cells, or neurons, to fire at once, for several milliseconds. This extreme mass-firing sends the brain into a panic. Neurons across the brain release neurotransmitters—the chemicals that carry signals between them. "It's like a very brief seizure," Hovda says. A sinister wave of electrical activity spreads across the brain as the flood of neurotransmitters, especially glutamate, tells neurons everywhere to fire even more. The cells scramble in vain to regain a normal, neutral state so they can be ready to fire again.

This scrambling consumes a lot of energy. But the neurons can't regenerate the energy they lose. The frantic firing causes the neurons to absorb excess electrically charged calcium and sodium and to spit

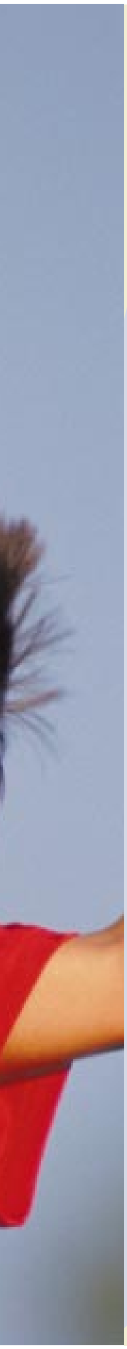
JOE PATRONITE *The Image Bank*

out potassium. The calcium clogs the mitochondria—the cell structures that make energy—preventing them from doing their job. So just when the neurons most need energy, they can't produce it.

Meanwhile the wash of calcium and potassium causes the brain's blood vessels to constrict, right when the neurons need more glucose from blood to fuel their attempts to recover. "We call this an energy crisis," Hovda says. A prolonged energy crisis can kill cells, resulting in permanent brain damage.

The extra sodium entering the brain cells can create more trouble, too. It makes them take in water—the way eating salty potato chips makes you thirsty. The water swells the cells, pushing them up against the skull. If the swelling is extreme, the expanding brain will start to crush itself against the skull; neurons, or even the entire brain, can die.

The cascade of chemical events peaks rapidly, but it takes a long time for the cascade to tail off and for the brain to settle neurons back to normal. Although no one knows quite how long is needed for the self-correction in humans, Hovda and his colleagues have done some suggestive studies in rats. Potassium, they found, rushes out of the cells for minutes, calcium rushes in for days, and sodium rushes in for hours to days. The constriction of blood vessels can also last for days. There is a damning aftereffect as well: once the brain manages to increase metabolism to meet the cells' high energy demands, it goes into a state of metabolic depression. The



A HEADS UP ON HEADERS

[redacted]

Concern about concussions in youth soccer has surged as rapidly as the sport's popularity has. Some scientists are now questioning the wisdom of "heading" the ball, at least for players under 12 years old. Others disagree, citing one study that found that by far the most concussions in soccer come from collisions with other players, especially when more than one are trying to head the ball.

"All of us suspect that the momentum of a ball on a young child's head, especially if it hits them when they're not ready, is a possible concussion scenario," says James P. Kelly, an expert in sports-related concussions who is based at Northwestern University Medical School. "But we have very little evidence that heading the ball per se is dangerous."

Also under debate is the long-lasting effect of years of headers. A 1999 study of amateur adult soccer players, swimmers and runners in the Netherlands (the average age was 25) found that on tests of memory and planning soccer players performed the least well. Some of the researchers concluded that the soccer players were suffering from chronic traumatic brain injury, or "punch-drunk syndrome," and oppose heading the ball on the basis of this study. Other scientists, however, think that factors such as head collisions and regular drinking could account for the lower scores.

Most physicians say that more testing is needed before concluding that headers should be banned, at a minimum for young players. But some concerned parents are clamoring for protective headgear, and entrepreneurial operations have surfaced to offer it. The armor varies from glorified cloth headbands to neoprene helmets. Whether they work, or are needed, is up in the air. *—P.S.*

brain "sort of gets exhausted," as Hovda describes it. The exhaustion lasts longer than the other chemical effects do.

The more severe the concussion, the longer the cascade continues. If a second concussion interrupts the brain's quest for equilibrium, Hovda says, a new cascade starts on top of the first one. The resulting damage is not just additive but multiplicative.

The chemical cascade helps explain the symptoms of concussion. "The cells in the brain have to fire in order for you to learn or remember something," Hovda says. "If they can't fire because they can't pump the chemicals where they have to go, or are exhausted, then you can't learn." Learning and retrieving information also require your cells to produce certain proteins. Protein synthesis takes energy—exactly what the concussed brain is short of. "It's not that the information isn't there," Hovda says. "It's that you can't access it."

Blows that twist the head—such as the elbow to Lindros's jaw or a right cross in boxing—cause worse harm than head-on hits. While setting off the chemical cascade, the wrenching action can also stretch or even sever neuronal pathways, adding permanent, local damage to the trauma.

Physicians try to treat certain symptoms of concussion by administering painkillers for headaches or antidepressants for some personality problems. But so far there's no effective treatment for the concussion itself except time. "I find it very depressing," Hovda says. "In the last 10 to 20 years there have been more than 25 clinical trials of treatments for head injury, and none of them have been successful. The problem is that the treatments target a particular part of the cascade. But no one knows how long these cascades last, so a drug given at one point may be beneficial but may be detrimental later."

THE MOST DANGEROUS SPORTS

The consequences of a concussion vary greatly from individual to individual. In their neuropsychological tests, Collins and Lovell found that athletes with learning disabilities such as dyslexia had greater cognitive deficits following concussions than their teammates did. Genes may also play a part. Barry D. Jordan, a neurologist at the Burke Rehabilitation Hospital in White Plains, N.Y., and his colleagues compared boxers who have *APOE∈4*, a gene associated with Alzheimer's disease, with boxers who have more common versions of the same gene. The *APOE∈4* fighters were more likely to suffer from chronic traumatic brain injury, sometimes called dementia pugilistica or punch-drunk syndrome.

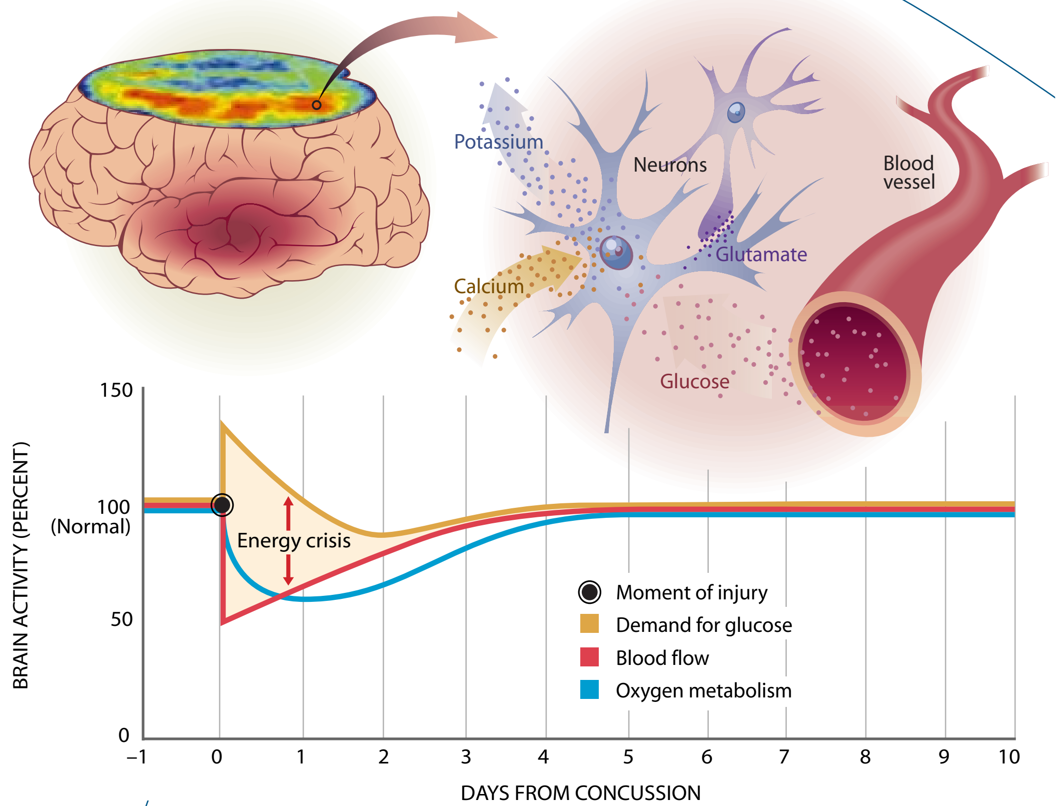
Hovda says that pregnant women may take a blow harder because they have extra blood circulating in their brains. And young people may react differently than adults. Some animal studies suggest that injury may lessen the brain's plasticity—its ability to learn new things and change—at least temporarily, especially in adults.

The threat varies from sport to sport, of course. In a three-year study published in September 1999, John W. Powell and Kim D. Barber-Foss, then at Med Sports Systems in Iowa City, studied concussions in varsity athletes from 235 high schools. Of the 10 sports they tracked, boys' football accounted for the most brain injuries by far—63.4 percent of 1,219 reported concussions. Boys' wrestling ranked second, with 10.5 percent. Soccer and basketball for both sexes were the next most dangerous. At the bottom was girls' volleyball, with only six concussions, or 0.5 percent. (The study didn't look at girls' football, girls' wrestling or boys' volleyball.)

Equally interesting are the patterns of brain injury within a sport. Football is hardest on quarterbacks; their concussion rate was nearly twice that of run-

Anatomy of a Concussion

[redacted]



A blow to the brain sets off a flood of neurotransmitters such as glutamate. This prompts neurons to fire incessantly, causing an influx of calcium into the neurons and a release of potassium. To keep firing, the neurons demand extra energy, but the excess calcium reduces oxygen metabolism and thus the cells' ability to generate it. Meanwhile the wash of potassium constricts blood vessels, limiting the supply of new glucose fuel. The high energy demand, restricted blood flow and oxygen debt create an energy crisis that exhausts the neurons, leading to the mental confusion and failed memory of concussion. The brain may take days to restore the chemical balance that constitutes full recovery.

SAMUEL VELASCO

SOURCE: David A. Hovda, UCLA School of Medicine

HOW SERIOUS A BLOW?

[redacted] The American Academy of Neurology has issued the following guidelines for recognizing and managing sports-related concussions:

GRADE 1

Symptoms: No loss of consciousness; transient confusion; mental-status abnormalities last less than 15 minutes.

Management: Remove the athlete from the activity; examine immediately and at five-minute intervals. Allow to return to sports that day only if symptoms resolve within 15 minutes. Any athlete who incurs a second Grade 1 concussion the same day should be removed from sports until symptom-free for one week.

GRADE 2

Symptoms: No loss of consciousness; transient confusion; mental-status abnormalities last longer than 15 minutes.

Management: Remove the athlete from the activity; examine frequently to assess the evolution of symptoms. Get more extensive, diagnostic evaluation if symptoms persist or worsen for longer than one week. Remove from sports activity until symptom-free for one week. Any athlete who incurs a Grade 2 concussion subsequent to a Grade 1 concussion on the same day should be removed from sports until symptom-free for two weeks.

GRADE 3

Symptoms: Loss of consciousness, either brief (seconds) or prolonged (minutes or longer).

Management: Remove the athlete from sports until symptom-free for one week if the loss of consciousness is brief, for two weeks if the loss of consciousness is prolonged. If still unconscious or if abnormal neurological signs are present at the time of initial evaluation, the athlete should be transported by ambulance to the nearest emergency department. If a subsequent brain scan shows brain swelling, contusion or other intracranial pathology, the athlete should be removed from sports for the season and be discouraged from returning to contact sports.

BLURRY CHOICE: A ban on boxing could reduce cases of brain damage—or send the sport underground, where fighters would be even less protected than they are now.

BRUCE AYRES *Tony Stone Images*

ning backs and more than twice that of linebackers. Most concussions in soccer came from collisions with other players, especially when more than one tried to head the ball. For all the sports except volleyball, the injury rate was up to 14 times greater during games than during practice. That makes sense, because players go at it harder and may be less likely to worry about protecting themselves when the score is at stake. And athletes who sustained more than one concussion tended to get their second in the same season as the first, rather than later—perhaps because of impairment from the first concussion.

High on everyone's list of treacherous sports is boxing. "I'm certainly on board with the American Medical Association, the American Academy of Neurology and various other physician groups that for 20 years have called for a ban on boxing," Kelly says. "The goal is to produce brain injury in your opponent before he produces it in you. We don't think that's a sport." But Jordan counters that "if boxing is banned it'll go underground, and the potential for injury will be horrendous. The general public has no idea how destructive that would be. In New York State, [unlicensed] boxing was banned during the 1920s. There was boxing going on in basements and in bars, with no safety rules or controls, and people gambling on the outcome. We don't want to go back to that."

Doctors agree that the benefits of playing most sports far outweigh the risks. "Most of us are interested in making sports safer and elevating the level of competition so that it is not just one step away from a brawl," Kelly says. Equipment can help. Helmets should fit properly and be hard, so that blows bounce off rather than twist the head. Mouth guards can absorb force and reduce it from the joint of the jaw. Training can help, too; athletes should work on their neck muscles, because a strong neck can carry the force of a blow away from the head into the torso.

Leagues should also impose rules that emphasize head safety, and referees should enforce them. But most of all, doctors, coaches, trainers, parents and athletes themselves need to understand the symptoms of concussion so that they can guard against the dangers posed by repeat blows to the head. After all, we're not like cartoon characters who can survive any number of anvils dropped on the head. For thousands of sports enthusiasts as well as pros, paying close attention to those seemingly minor symptoms will help protect the athlete's most important piece of gear: the brain.

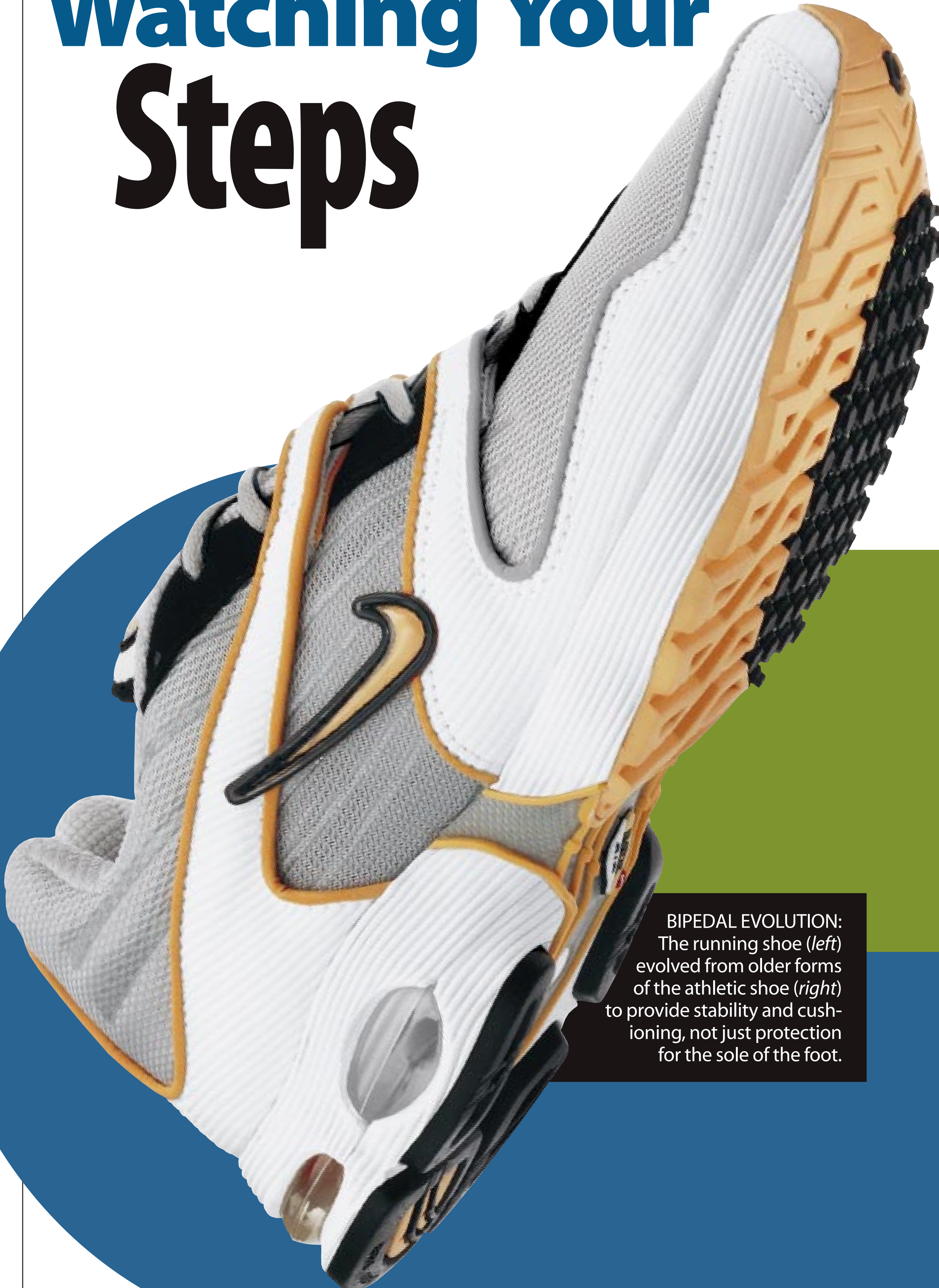
POLLY SHULMAN is a science writer in New York City and a Sunday book critic for *Newsday.*

FURTHER INFORMATION

A collection of articles on brain injury in high school, college and professional athletes can be found in the *Journal of the American Medical Association,* Vol. 22, No. 22; September 8, 1999.

The Brain Injury Association's Web site on concussion is available at www.biausa.org/sportsfs.htm, and the American Association of Neurology concussion Web site can be found at www.aan.com/public/concussionsportsindex/sportsconcussion.htm

Watching Your Steps



BIPEDAL EVOLUTION: The running shoe (*left*) evolved from older forms of the athletic shoe (*right*) to provide stability and cushioning, not just protection for the sole of the foot.

A new appreciation of the diversity of running styles may eventually yield shoes custom-fit to their wearers

by Karen Wright

Running is often called a "pure" or "simple" sport. It doesn't have many rules, it doesn't take much teamwork, and it requires little in the way of equipment, training and talent. Almost anybody with two legs and a healthy heart can run, almost anytime and almost anywhere. There is, of course, a yawning chasm between recreational joggers who log a few miles after work and the cabal of athletes who win marathons and Olympic medals. But just about everybody who runs farther than to the bus stop uses the one and only piece of specialty gear the sport demands: running shoes.

Most people can't imagine running without them. Casual athletes wear running shoes to protect against injury by cushioning impact and aiding joint alignment. Serious runners count on their shoes to improve their performance as well. How and whether running shoes deliver on these expectations are questions science has been trying to answer since the word "sneaker" went the way of the hula hoop sometime in the 1970s. After decades of investigation and millions of dollars of investment, the running shoe is still very much a work in progress. In fact, its brief history can be seen as an ongoing experiment in biomechanics, materials and design.

Elite runners' quest for better fit, better protection and better times has driven a technological renaissance that has reached far beyond the track. Its repercussions can be felt today in most specialized sports footwear and even the humblest walking shoe—not to mention the wallet. Meanwhile all the brainpower and high-tech analysis brought to bear on the running shoe in recent years have been toppling some cherished assumptions. The roles of impact and alignment in running injuries and athletic performance turn out to be more subtle and complex than anyone expected. But some of the latest lessons to come off the treadmill are surprisingly simple: Bare feet know best. Go with what feels right. And when it comes to running shoes, one size—or style or shape or sole—will never fit all.

"Shoe companies wage a constant battle to get a shoe with an adequate amount of both shock absorption and stability," says Jack Taunton, co-director of the University of British Columbia's Allan McGavin Sports Medicine Center. As the leader of major studies tracking thousands of runners' injuries over the past three decades, Taunton is well acquainted with the classic trade-off between the two aims. Shock-absorbing materials such as trapped gas, silicone gel and foam polymers cushion the impact of pounding feet, long blamed for the most insidious running injuries. But too much cushioning compromises a shoe's ability to stabilize the alignment and movement of the joints in the legs and feet. Taunton attributes a rise in Achilles tendinitis in the late 1980s to a concomitant increase in the popularity of soft heels in running shoes. "When the heel gets too soft, the foot sinks into it and torques, and then you get more Achilles problems," he explains.

CONTROLLING ROLL

Stability features such as stiffer soles, racing stripes and arch supports are meant to steady the foot within the shoe and guide its contact with the ground. But a shoe that's too rigid won't protect against impact and can restrict the complex series of motions that make up a normal gait cycle. These days, for ex-

COURTESY OF NIKE INC. (*left*) AND CONVERSE INC. (*right*) ample, many running shoes have a built-in support called the dual-density midsole, a polymer layer between the outsole and insole that is firmer under the arch than along the outer side of the shoe. The firm arch was designed to prevent excessive pronation, or inward rolling of the foot, as the runner's weight shifts from heel to toe.

But some amount of pronation is natural and even necessary in normal walking and running. After the dual-density midsole was introduced in the early 1980s, Taunton says, he saw a sizable increase in the frequency of iliotibial-band friction syndrome, a condition in which a band of connective tissue running down the outside of the thigh rubs painfully against a bony protrusion near the knee. Taunton thinks that the early dual-density technology may have caused normal pronators to roll too far onto the outer edges of their feet—a motion called supination that is also part of normal running but that can be harmful in excess. Oversupination stretches the iliotibial band and causes the long bone of the thigh to twist inward, increasing the friction between the band and the bony knob.

Manufacturers also wage the battle between cushioning and stability in their efforts to reduce the weight of their shoes, because stability components tend to be heavy. "We're constantly trying to get the shoes lighter-weight without making them too flexible," says Martha Sutyak, design manager of New Balance Athletic Shoe in Boston. The biggest breakthroughs in strong, lightweight materials happened decades ago, during the chemical revolution, when nylon replaced leather and canvas uppers and the now ubiquitous foam polymer called ethylene vinyl acetate (EVA) supplanted rubber in the midsole and heel. Since those innovations, most progress in weight reduction has consisted of removing unnecessary material—strategically carving out the surplus EVA in perforated midsole designs such as New Balance's "stability web" or Saucony's "grid" technology.

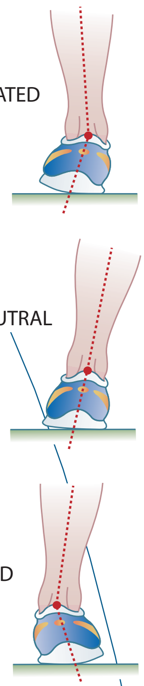
BAD VIBRATIONS

While shoe manufacturers struggle to strike the right balance between cushioning and stability, biomechanics research is challenging fundamental assumptions about the roles of both. At the University of Calgary's Human Performance Laboratory, director Benno M. Nigg has marshaled evidence that the jarring effects of road running may not be nearly as pernicious as once thought. Nigg says he himself needed to be convinced: it's clearly more comfortable to run in track shoes than in brogans. But when he set out to quantify the relation between impact forces and running injuries, Nigg found that there wasn't one. His tests showed, for example, that fast runners land with two or three times the force of slower runners and yet are injured no more frequently. In fact, the runners who experienced the highest-impact forces had fewer injuries than the lowest-impact runners did.

Nigg cites similar results from other labs. It turns out that running on hard surfaces produces no more

Stylistic Differences

[redacted]

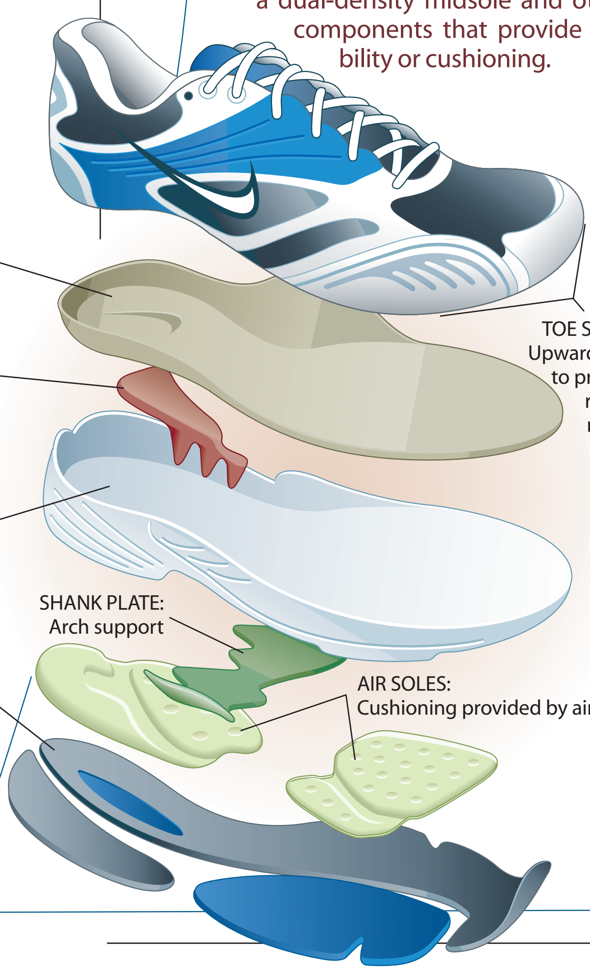


The right foot of three different runners during the middle of a step makes contact with either the outside of the foot (supinated), the entire surface (neutral) or the inside of the shoe (pronated).

Summing the Parts

[redacted]

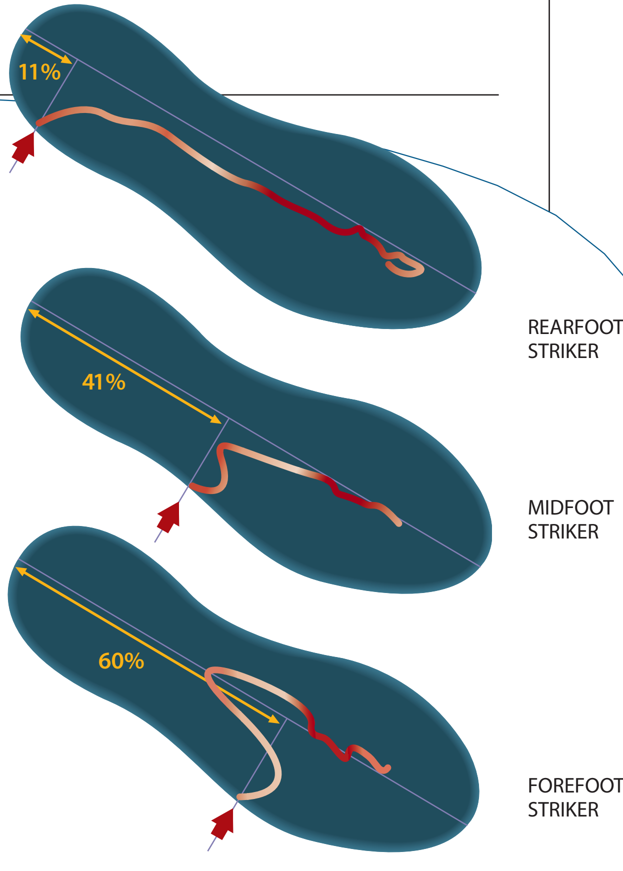
The Nike Air Structure Triax 5, a recent typical running shoe, contains a dual-density midsole and other components that provide stability or cushioning.



SAMUEL VELASCO

Pressure Points

Rearfoot, midfoot and forefoot strikers land on different places on the outside of the right foot (*arrows*). The red band traces how the center of pressure tracks along the foot. The percentages show how far from the heel contact is first made.



SAMUEL VELASCO

injuries than running on soft surfaces. Impact exercises such as basketball, gymnastics and running have been found to increase bone mass and integrity more than swimming and other low-impact activities do. And although it's reasonable to suppose that degenerative joint diseases such as osteoarthritis would afflict runners more often than nonrunners, they don't. "The concept of impact forces as a major source for running injuries is not well understood," Nigg concludes in a paper scheduled to appear in the *Clinical Journal of Sports Medicine*. "The paradigm of 'cushioning' to reduce the frequency or type of running injuries should be reconsidered." Contrary to prevailing assumptions, high-impact running has not produced an epidemic of injuries, Nigg says.

What, then, can account for the injuries that sideline up to two thirds of serious runners in any year? And why are cushioned shoes more comfortable than stiff ones? Nigg has proposed a novel explanation based on the vibrations in soft tissue that are generated when a runner's heel strikes the ground. His studies demonstrate that just before ground contact, muscles throughout the body tense up in order to counter soft-tissue vibrations. Thus, runners' flabby parts jiggle far less than predicted from impact forces: "The only part that jiggles are women's breasts, where you don't have any muscle," he says.

Furthermore, there's a so-called natural frequency at which each individual's soft tissue "wants" to vibrate, Nigg remarks. Just as guitar strings of different lengths and diameters resonate at different frequencies when plucked, so resonance occurs at different frequencies in different people. The natural frequency of a runner's body depends mostly on weight and muscle tone. And the cushioning in running shoes can amplify or damp soft-tissue resonance by shifting impact frequencies toward or away from a runner's natural frequency.

These variations help explain why individual runners have preferences for a particular shoe style. For each person, some shoes will increase soft-tissue vibrations, and others will decrease them. Nigg believes that fatigue and injury result when the muscles expend too much energy countering soft-tissue resonance. With the right shoe, that energy is freed up, and a runner can expect gains in performance of as much as 5 percent—the equivalent of eight minutes in a marathon.

Nigg's ideas still need to be backed up in the lab. But his theory is part of a growing body of research cataloguing the differences among runners' bodies rather than their common ground. Marathoner and biomechanist Peter Cavanagh first confronted the differences in running styles decades ago, when he began conducting analyses of ground-contact patterns in his laboratory at Pennsylvania State University. At the time, the prevailing model for ground contact in running was so simple it seemed obvious: a runner lands on his heel, rocks forward through his instep and then presses off from the forepart of the foot. The heel strike, with its associated impact forces, was considered the most treacherous phase of the gait cycle. Midstance, with its threat of overpronation, was also receiving considerable attention in shoe research and design.

Cavanagh used a force-sensitive platform embedded in a test track to quantify the location and magnitude of forces on the sole of the foot from heel strike to toe-off. His results surprised him. Sure enough, most of his runners did land on the back part of the foot. But they planted on the outside edge of the heel rather than the middle. Another group of runners, going the same speed, landed on their insteps, then shoved off from the forefoot. A third group both landed on and took off from about the front third of the foot. These groups would become known as rearfoot, midfoot and forefoot strikers, respectively. And within each group, Cavanagh found an infinite variety of ground-contact pat-

GAIT WATCHING: The University of Calgary's Human Performance Laboratory measures the forces on the sole throughout the different phases of a shoe's contact with a force-sensing platform (*foreground*), an action that is captured by tripod-mounted high-speed cameras.

BILODEAU/PRESTON

terns. "When studied in fine detail," he wrote in his 1980 classic, *The Running Shoe Book,* "the pattern of ground contact can be as individual as the runner's voice, something unique and identifiable."

Cavanagh's studies showed that running biomechanics were more complex and idiosyncratic than anyone had suspected. And he proceeded to question another tenet of track lore: the treachery of the heel strike. His data clearly indicated that the forces applied to the front part of the foot during toe-off could be several times greater than those associated with the impact of touchdown.

"At the time, running shoes were wafer-thin under the metatarsal heads," Cavanagh says, referring to the region where the toes meet the ball of the foot. "Our studies pointed to the fact that that needed to change. And it did change."

Today's running shoes are indeed padded from heel to toe. But the forefoot is still a vast terra incognita for many runners and manufacturers, who may have little interest in or knowledge of the contribution it makes to running. A good example is the toe spring, the slight upward curve of the sole at the front of almost all running shoes. "The thinking is that the running stride will be more efficient since there will be a natural rocking forward onto the forepart of the shoe," Cavanagh explained in 1980, when the toe spring was a new gimmick. "As far as I know, the evidence for this supposedly 'more efficient toe-off' does not exist except in the minds of manufacturers and inventors."

Twenty years later evidence of the toe spring's efficacy is still lacking. Now the philosophy of many manufacturers is shifting to favor a more relaxed, flexible forefoot, made with soft materials and strategically placed grooves on the sole to allow toe-off the way nature intended. Nigg's colleague Darren Stefanyshyn has shown recently that toe springs may actually interfere with propulsion by preventing the toes and the balls of the feet from pushing fully down against the ground. "We just constructed a shoe that doesn't have [the toe spring], and we increased sprinting time in the average runner by two tenths of a second," Nigg claims. Because Nigg works closely with athletic-shoe manufacturer Adidas, his views on the toe spring may soon be reflected on retail shelves.

RUNNING INTO A BRICK WALL

Changing ideas about stability and alignment are also challenging running-shoe features designed to control pronation. At the Nike Sports Research Laboratory in Beaverton, Ore., scientists have come to question the use of rigid devices such as dual-density midsoles and footbridges. Such devices create abrupt barriers to the natural inward rolling of the foot, says lab director Mario Lafortune: "It's like trying to stop pronation with a brick wall." That strategy has become less desirable as research such as Cavanagh's has demonstrated that some pronation is normal and even necessary to transfer weight from the outside edge of the foot, where most people land, toward the foot's midline.

Instead of blocking pronation, Lafortune says, he and his colleagues are trying to slow it down. Sudden pronation is more forceful and potentially harmful than gradual pronation, he explains, and some simple modifications to existing shoes can ease the passage. The "crash pad" on the outside edge of the heel can be softened to compress more easily, so that the foot isn't rushed out of its mildly supinated landing position. Similarly, the midsole in the rear third of the shoe can be thinned and rounded toward the outside edge. Nike has already incorporated these adjustments in several retail models, and last year Asics released its first shoe designed to slow the rate of pronation.

And in addition to using external devices to stabilize alignment, Lafortune's team is looking for ways to enhance the foot's natural rigidity. In barefoot running, that rigidity is supplied by the windlass mechanism, a tightening of the bands of connective tissue that run between the heel and the base of the toes. When the toes bend back during toe-off, the bands become taut, locking the long bones of the foot, deepening the arch and causing a slight resupination that centers the foot for push-off. A foot that is both rigid and resupinated provides the safest and most efficient propulsion, Lafortune maintains. And it's best to let the foot stabilize itself rather than to impose stability through rigid elements in the shoe.

CHAMPIONING BARE FEET

Lafortune is reluctant to share how Nike plans to harness the windlass mechanism in upcoming designs. But, again, a softer and more flexible forepart is probably in the works. And barefoot movement is becoming a byword in biomechanics labs outside Oregon. Based on his studies comparing runners' alignment with and without shoes, Nigg—who pioneered the dual-density midsole—now doubts the wisdom of aggressive measures to correct overpronation. For one thing, no one has determined how much pronation is too much; what counts as excessive seems to vary from person to person. Nigg thinks each body has a preferred pattern of movement, revealed in barefoot running, that it adheres to despite orthotic intervention. If shoes promote that preferred alignment, they'll feel great and improve performance; if they work against it, they'll irritate and exhaust the runner. But there's no single, ideal skeletal alignment for running and no systematic corrective strategy that will work for all runners. "That's why if you go to five podiatrists, show them your feet and tell them what you do, you'll get five different [shoe] inserts," Nigg says.

As the running-shoe paradigm dissolves into relativism, how can the average runner hope to find the right shoe? The time-honored method of trial and error is actually quite effective, explains Nigg: "There's a very high correlation between what people call comfortable and where the muscle work is minimal."

But reinforcements may be on the way. Nigg has already approached manufacturers with a plan to group all shoe models according to parameters such as degree of cushioning, dynamic alignment and shape, so that runners who have found a shoe that works for them can readily identify other models with the same properties. Nike is hoping to persuade running-specialty stores to perform biomechanical analyses that would characterize customers' running styles. Microelectronic sensors in shoes could monitor properties such as pressure and compression, Cavanagh says, and change cushioning and stability features to accommodate different body weights, running surfaces and patterns of ground contact.

Even if shoe producers pass the baton to microchips, the market is likely to continue to offer a bewildering array of choices. It all seemed so much simpler 30 years ago, when the late, legendary University of Oregon track coach and Nike co-founder Bill Bowerman cooked his first rubber sole on a waffle iron. Perhaps the trouble is that the history of running is so much longer than the history of the running shoe.

At some point soon after the demise of knuckle walking, running must have become essential to the survival of the human species, whether it was running after or running from. The idea of recreational running is a newer invention, and the running shoe is younger still. "We're always busy testing advanced concepts and technologies, but those always have to do with the same old problems: cushioning, stability and fit," says New Balance's Sutyak. Like a long-distance runner circling a one-mile track, running shoes will keep coming back to the starting line.

BENNO M. NIGG *University of Calgary*

QUO VADIS? Markers attached to a runner's leg reflect light so that high-speed cameras can determine leg and foot positions.

KAREN WRIGHT is a longtime science writer and a former editor at *Scientific American.*

FURTHER INFORMATION

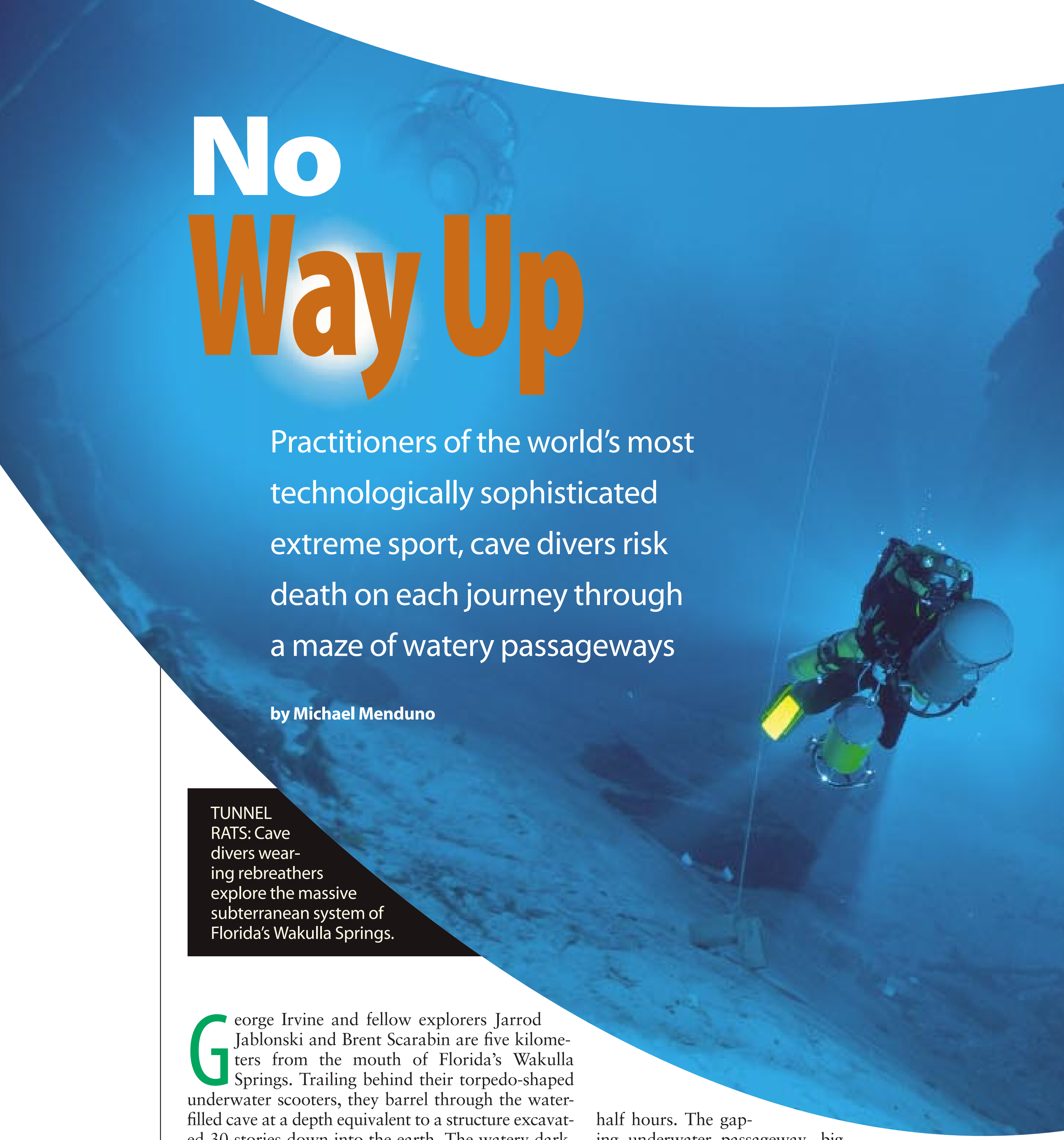
RUNNER'S WORLD COMPLETE BOOK OF RUNNING: EVERYTHING YOU NEED TO KNOW FOR FUN, FITNESS AND COMPETITION. Amby Burfoot. Rodale Press, 1999.

IMPACT FORCES IN RUNNING. Benno M. Nigg in *Current Opinion in Orthopaedics,* Vol. 8, No. 6, pages 43–47; November/December 1997.

No Way Up

Practitioners of the world's most technologically sophisticated extreme sport, cave divers risk death on each journey through a maze of watery passageways

by Michael Menduno



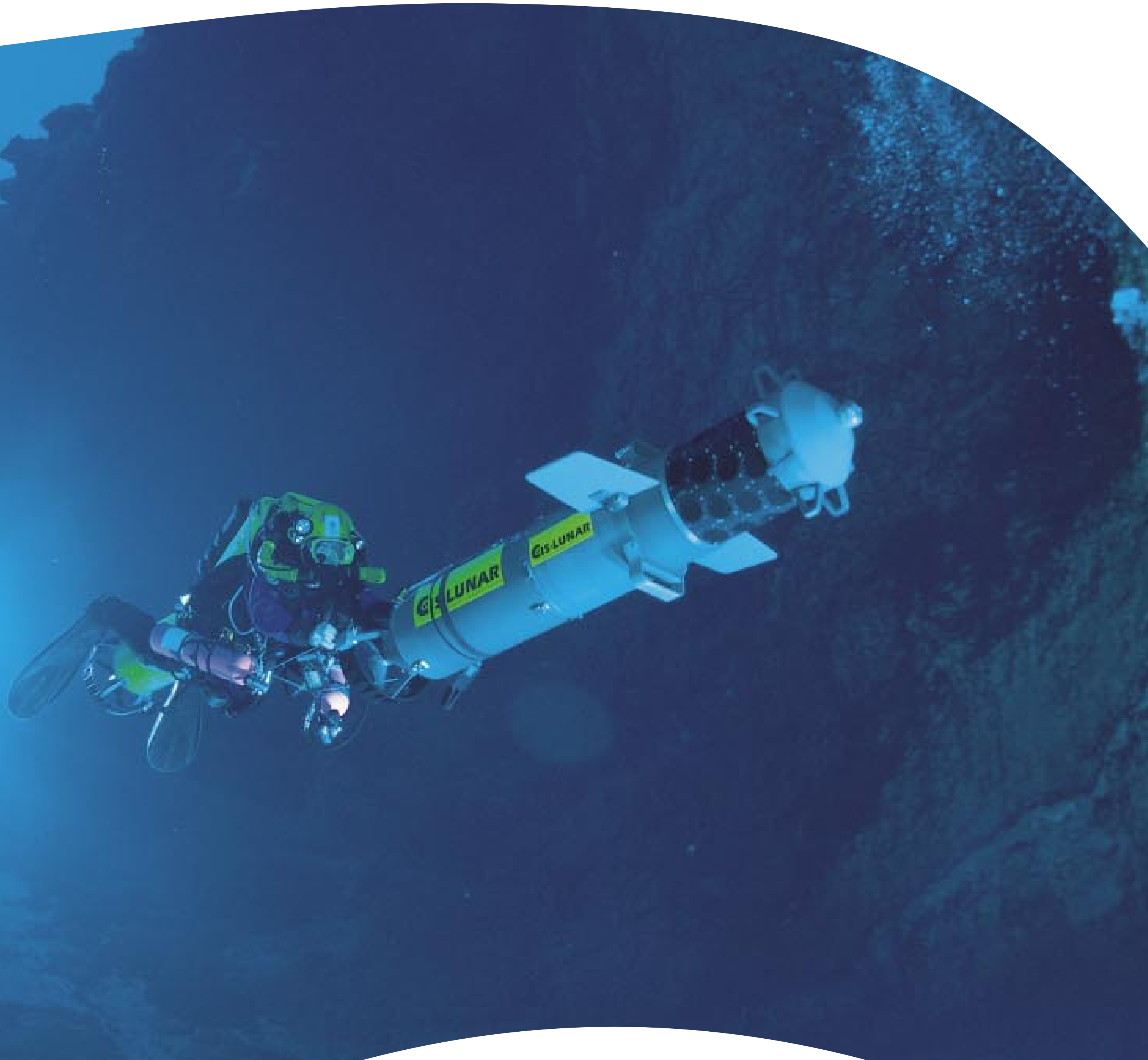
TUNNEL RATS: Cave divers wearing rebreathers explore the massive subterranean system of Florida's Wakulla Springs.

WES SKILES *Karst Productions*

George Irvine and fellow explorers Jarrod Jablonski and Brent Scarabin are five kilometers from the mouth of Florida's Wakulla Springs. Trailing behind their torpedo-shaped underwater scooters, they barrel through the water-filled cave at a depth equivalent to a structure excavated 30 stories down into the earth. The watery darkness presses in around them, swallowing the beams of their 100-watt arc lamps. The recesses of the submerged limestone tunnel have not been illuminated in the millions of years since the sedimentary rock accreted from the remains of dead sea creatures.

After descending for 30 meters through the clear waters of a lake to the cave entrance, the daredevil crew has motored in formation for more than two and a half hours. The gaping underwater passageway—big enough to accommodate a taxiing 747—shows no signs of narrowing as the men press on with their mission of finding the elusive source of the waters that well up to the surface, where bald cypress trees line the shore and alligators make their home.

Each of the divers wears a back-mounted life-support system called a rebreather, similar to those used by astronauts. Rebreathers recycle their air supply by re-



moving the exhaled carbon dioxide and adding supplemental oxygen, extending the time divers can stay underwater by a factor of eight to 10, compared with ordinary scuba gear. They are taking in a mixture of oxygen, helium and nitrogen designed to prevent the epilepticlike seizures and narcosis caused by inhaling compressed air beyond a depth of 65 meters. Even so, the men remain hyperalert; if any equipment fails at this point in the dive, they could lose their lives.

Their biggest fear: a rebreather problem that would force them to switch to their backup scuba systems. At their current 90-meter depth, a scuba cylinder might last 10 to 12 minutes, as opposed to 120 minutes near the surface, a consequence of the pressure, which is 10 times that above. As a precaution prior to the dive, the team's support divers set a supply line partway along the route, placing 30 scuba tanks along a length of four kilometers. These backup cylinders are cached at 400-meter intervals. Theoretically, this should give them enough gas to return to the surface in the event that their rebreathers fail. A scooter failure is less threatening. Each explorer began the dive towing four backup scooters, which each have a burn time of two and a half hours. When the batteries on their operating scooter reach the halfway point, they switch to a fresh machine, depositing

DEEP LOGISTICS: Support divers assist recently returned exploration divers who are decompressing inside the nearby chamber.

STEVEN AUER

the spent one along the way and then picking it up on their return journey.

Jablonski is in the lead, paying out line from a handheld reel while carefully motoring a meter off the cave floor to avoid stirring up the silt. The thin nylon cord is tied off to one of the guidelines that the Woodville Karst Plain Project (WKPP) team installed on a previous dive—one of dozens they've made to reach this point in the cave. The network of lines snakes through the maze of chambers and massive tunnels, forming a continuous trail that leads back to the entrance. Without it, the team would very likely be unable to find its way out.

Irvine's third scooter is running low on power. He signals to his partners that it's time to turn the dive. Jablonski finds a small outcropping near the floor of the cave and ties off the line. They've been scootering for 170 minutes and have covered five and a half kilometers, surpassing their previous world-record distance by more than a kilometer. Although others have gone deeper, no one has penetrated an underwater cave this far from its entrance.

Getting there is just half the challenge; the most important part of the dive lies ahead: the three-hour return transit to the cave entrance, followed by an eight-hour staged ascent, or decompression, needed to adjust to the reduction in pressure. A direct ascent to the surface would almost certainly cause paralysis or death. During the decompression, the team will ascend in timed, three-meter increments up to the entrance, beginning at a depth of 75 meters—almost twice the maximum 40-meter depth limit recommended for recreational divers. As they climb, they will alter their gas mixtures five times to accommodate the different stages of decompression. They emerge from the water around 8 P.M., almost 14 hours after they began their dive.

Expedition-level cave diving is arguably one of the most high-tech sports on the planet. It's also one of the most dangerous. Pioneering cave explorer Sheck Exley, who died in 1994 during a 300-meter-deep cave expedition, called it an exercise in "controlled paranoia." Asked once what motivated him to explore underwater caves, Exley replied, "You can't see what's in the back of a cave unless you go there."

Few people have the skill, time and financial resources to tackle a dive as complex as the WKPP's 1998 world-record penetration—it required over $300,000 worth of equipment and a support team of more than a dozen divers. Even basic cave diving requires a commitment to training and equipment that far exceeds that of the typical recreational diver. The endeavor is part of the fastest-growing segment of sport diving: technical diving, which encompasses forays into shipwrecks and dives to great depths. Think of it as sport diving's version of extreme skiing. Whereas recreational diving is restricted to no-decompression journeys at depths not exceeding 40 meters in open waters, technical divers are limited only by their training, equipment and experience.

Unlike their open-water counterparts, cave divers do not have direct access to the surface in an emergency. Any problems they encounter must be solved underwater. The big risk is running out of air and drowning, which can occur as a result of panic, poor planning, a catastrophic equipment failure or getting lost in a cave, a major cause of cave-diving fatalities. Cave divers depend on their line for navigation and carry three lights, because there is no ambient illumination. "Silt-outs" are another hazard that can make navigation difficult. Although the water in most spring-fed caves is crystal-clear, disturbing the settled powdery layer of silt and clay can cause visibility to drop instantly from tens of meters to zero, rendering the diver virtually blind.

WATERY GRAVES

According to statistics kept by the National Speleological Society's Cave Diving Section, an estimated 480 people have died in underwater caves since 1965. Actual incident rates are hard to calculate because no one knows exactly how many people participate in the sport or the number of dives made. Although more than 5,000 divers have completed some level of cave training over the past five years, underground veterans estimate that there are only about 1,000 active cave divers in the world. In comparison, there are approximately three million recreational divers in the U.S., among whom about 100 deaths a year occur, according to Diver Alert Network statistics. In 1994 Jeff Bozanic, who coordinates accident files and statistics for the Cave Diving Section, estimated that one out of every 100 trained cave divers would die in an accident. This figure is probably lower today, he says, because of the increasing number of divers being trained, as well as better techniques and equipment.

One of the primary causes of mishaps is the lack of proper training. Today cave-diving courses are available through both the National Speleological Society and the National Association for Cave Diving. A number of technical-diving training agencies also offer cave certification. A cave-diving course runs 50 to 60 hours and requires that the diver be certified as an advanced open-water diver and have completed a minimum of 50 dives. The course includes 15 supervised cave dives and can cost from $1,200 to $2,000. In addition, there are specialty courses to train divers on the proper use of scooters, alternative gas mixes and rebreathers. But even trained cave divers are not immune to accidents, which are almost always fatal. In 1999, for example, there were six fatalities; five of those who died were cave certified. In virtually all these accidents, the divers violated one or more of the major safety principles of the sport, such as poor gas planning: cave divers should use no more than a third of their gas for the penetration leg of their journey and reserve two thirds for their return trip—enough for two divers to make it out of the cave should one suffer a catastrophic air failure.

Although overall safety has improved, in recent years there has been an increase in technology-related fatalities. Lured by easy access to advanced technologies such as scooters and complex gas mixtures, some divers push harder than their experience warrants. "Today the big dives are easy to do; that's part of the problem. There's a wealth of information on the Internet, and the technology is readily accessible," explains Lamar Hires, a former training director for the Cave Diving Section.

Hires is concerned that divers are trying to move too fast. As an example, he cites the double drowning that occurred last November when two inexperienced cave divers scootered a kilometer into Madison Blue Springs in Madison, Fla., became disoriented, panicked and drowned. One of them still had gas in his tanks when his body was recovered. "In the past, divers had to work up to these dives," Hires says. "Now they don't seem like such an ominous mountain to climb. Unfortunately, divers confuse knowledge with experience."

$10,000 ON YOUR BACK

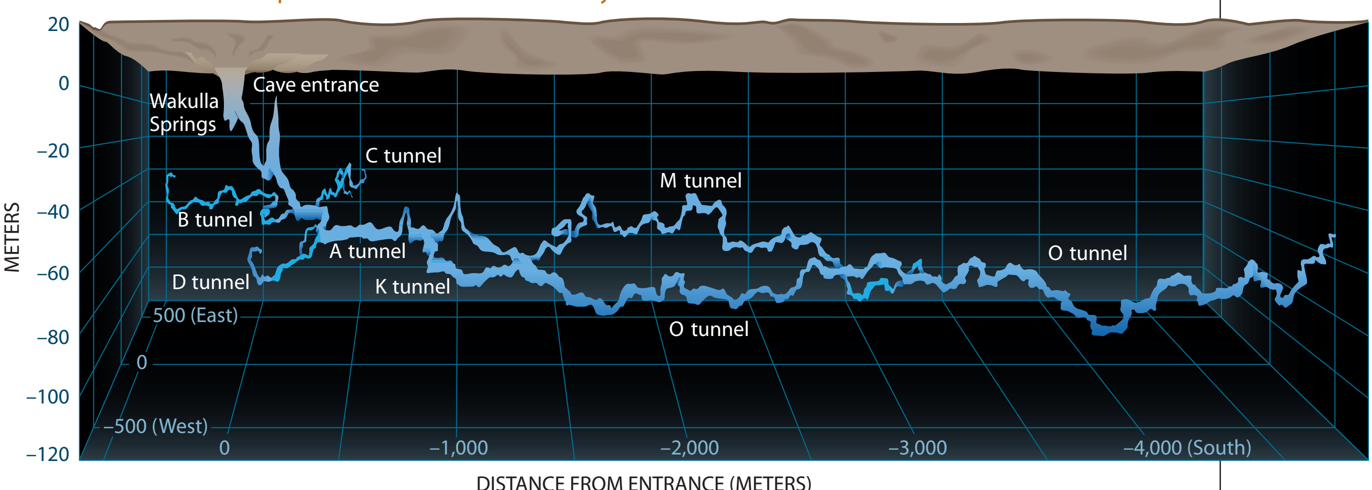
To survive in a hostile environment, cave divers require far more equipment than do their open-water counterparts—it's not uncommon for someone to enter the water with $10,000 worth of gear. The key is having a backup for all critical life-support equipment. Experience has shown that if a piece of gear can fail, then it will, at the worst possible time.

The most important thing on a diver's back is, of course, the breathing system. Compared with recreational divers, who typically carry a single 2,200-liter aluminum tank, cave divers usually descend with a minimum of 6,800 liters of breathing gas carried in dual back-mounted tanks called doubles. The doubles are connected by a manifold and have a primary and a backup demand regulator—a mechanical device that enables breathing underwater.

In addition to their doubles, cave divers often carry one or more 2,200-liter side-mounted tanks, called stage bottles, that are filled with their decompression gas mixture. They can also be used to extend a diver's main gas supply. Divers maintain neutral buoyancy (floating in water at the desired level) by inflating a buoyancy-compensating device called wings, a sealed, U-shaped bag that is mounted on the diver's backpack and can be inflated by means of a valve to achieve the appropriate amount of lift. Yet swimming through the water with up to 100 kilograms of equipment can slow one's pace. For that reason, many cave divers prefer to ride on battery-powered underwater scooters that allow them to travel farther and conserve energy and so exhaust their tanks less.

Mapping Netherworlds

Wakulla Springs extends for kilometers, as the WKPP group has charted in this map. The full extent of the cave system is still not known.



SAMUEL VELASCO; SOURCES: WKPP AND TODD R. KINCAID *Hazlett-Kincaid, Inc., and Global Underwater Explorers*

To avoid getting hypothermia during their lengthy dives, Florida cave divers rely on watertight dry suits with fleece or Thinsulate underwear. The garb is typically inflated with argon gas carried in a thermos-size cylinder to provide an extra layer of thermal protection against the chill 20 degrees Celsius water. Neoprene wet suits are usually adequate in the warmer cave systems found in Mexico, Brazil and the Bahamas. The well-dressed cave diver also carries a variety of specialized equipment, including a primary 50- to 100-watt light and two backups. In the event of primary-light failure, the diver has a secondary light and a backup, at least one reel of line used for navigation, and a dive computer to monitor depth, time and decompression status, along with a backup set of decompression tables, a watch or timer, and a backup mask. Most cavers, however, rely on a low-tech solution for handling the call of nature: adult diapers.

A SPELUNKER'S APOLLO MISSION

Beyond its niche in television and film lore (it was the location of the movie *Creature from the Black Lagoon* and the TV series *Sea Hunt*), Florida's Wakulla Springs holds nearly iconic status among cave divers. Off-limits to anyone who does not hold special (and hard-to-get) permission from the state, the gigantic spring system is considered the birthplace of technical diving, and its poster child is Bill Stone. In 1987 the structural engineer pulled off technical diving's equivalent of the Apollo moon shot when he pioneered the use of mixed-gas technology for deep cave exploration at Wakulla. Using helium-based breathing gases in place of air, as well as scooters and an experimental rebreather, Stone and his team mapped nearly 3.3 kilometers of underwater passages at depths exceeding 80 meters, far beyond the realm of ordinary scuba. Although the technologies were not new—they had been used by commercial and military divers for more than 20 years—they had never been applied to sports diving. Today, thanks to Stone, mix technology has become commonplace among cave divers, and rebreathers are starting to be used for cave exploration.

Despite its availability and low cost, compressed air—a mixture of about 21 percent oxygen and 79 percent nitrogen—has several disadvantages as a diving gas. Because nitrogen is absorbed by the lungs at increased pressure, its presence in air limits the time a diver can stay underwater without having to decompress. In addition, the nitrogen becomes increasingly narcotic beyond about 30 meters, impairing a diver's ability to perform underwater. Some early diving textbooks compared the effect to that of drinking a martini for every 15 meters of depth. Beyond about 60 meters, the oxygen in air also becomes toxic as a result of the pressure, which is more than seven times that at the surface. This can lead to epilepticlike seizures, resulting in unconsciousness and, subsequently, drowning.

To avoid these physiological problems, cave divers rely on one or more special gas mixes. For dives of less than 40 meters, divers typically use "enriched air nitrox," an oxygen-nitrogen mixture whose oxygen fraction varies from 23 to 50 percent, depending on the depth of the dive. By increasing oxygen levels, divers inhale less nitrogen and therefore reduce their decompression requirements, because less nitrogen is absorbed by the body. When diving beyond 60 meters, they often breathe a mixture of oxygen, helium and nitrogen, called "trimix," whose oxygen fraction is lower than that of air, to avoid the problems of oxygen toxicity. Nonnarcotic helium is substituted for some or all of the nitrogen, enabling the divers to effectively set the amount of narcosis they're willing to tolerate. In the midrange between about 40 to 60 meters, air is close to optimal, and the narcosis is manageable for an experienced diver.

In addition, divers usually take in a nitrox mix and pure oxygen during their decompression to help eliminate the excess helium and nitrogen absorbed by their body during the dive. Although mix technology offers divers numerous advantages, it comes at the price of increased planning, logistics and cost.

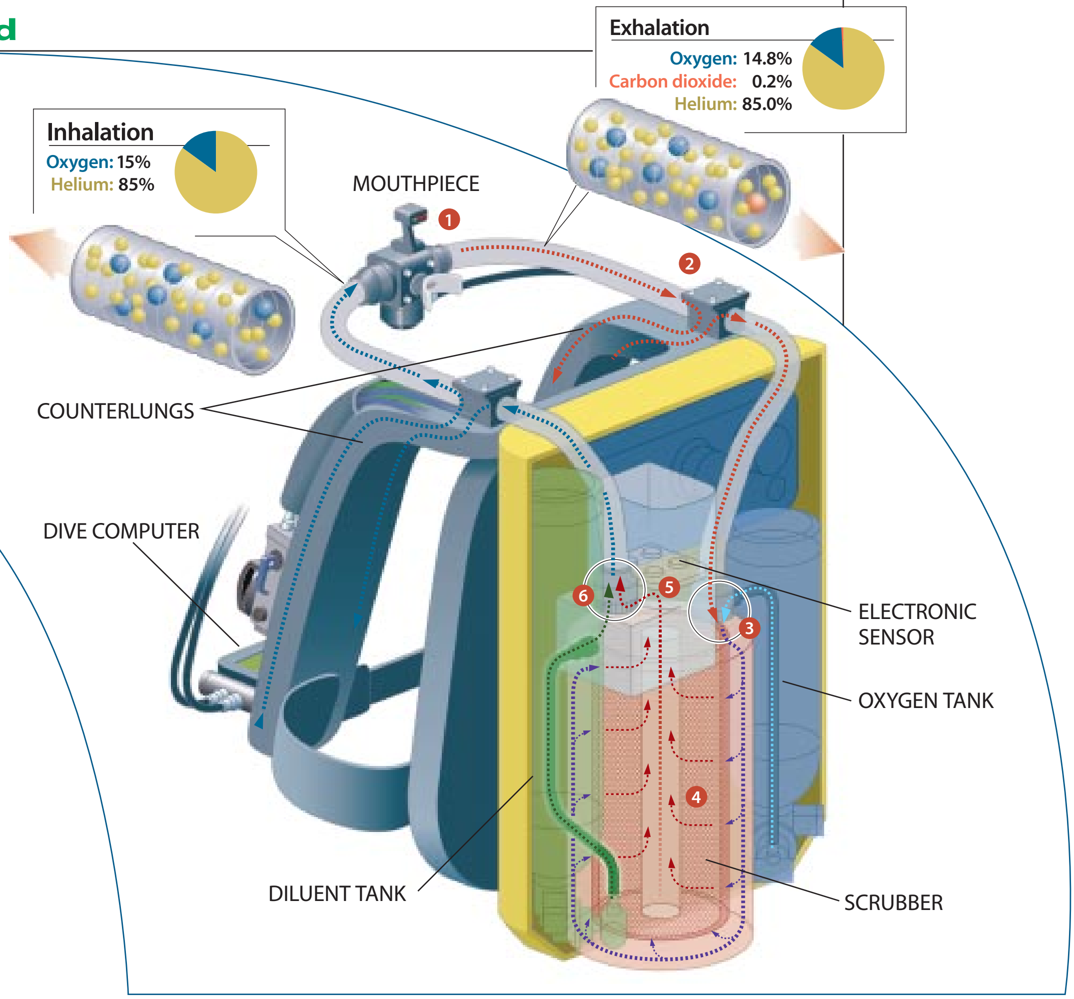
Rebreathers are the latest item in a cave diver's equipment locker. By greatly extending the time a diver can stay underwater, rebreathers make it possible for cave divers to travel farther and deeper. But because of their complexity and expense—a mixed-gas rebreather can run from $7,500 to $20,000, depending on the model—they have not been employed by many divers. First conceived of by 17th-century technologist Giovanni Borelli, rebreathers have long fascinated the diving community. Although the first

MORE THAN YOUR WEIGHT: Cave divers carry up to 100 kilograms of equipment, including extra breathing tanks and scooters.

WES SKILES *Karst Productions*

What Goes Around

An electronic closed-circuit rebreather recycles a diver's exhalations, extending a gas supply up to 40 times longer than conventional scuba's. Exhalations through the mouthpiece (*1*) pass through a counterlung in the strap that ensures a sufficient volume of gases (*2*). Oxygen is added (*3*) before the gas passes through a scrubber (*4*) that removes carbon dioxide. An electronic sensor (*5*) monitors the oxygen before the addition of a helium-and-oxygen diluent (*6*) provides a breathable blend of gases tailored for dives at great depths.



SAMUEL VELASCO

working unit was invented in 1876, the technology wasn't deployed in appreciable numbers until World War II, when its utility in war proved its value. The absence of bubbles and extended range of closed-circuit rebreathers enabled combat swimmers to penetrate behind enemy lines. Twenty years later doctoral-candidate-turned-inventor Walter Starck introduced to consumers the Electrolung, the first electronically controlled rebreather. Within a year, however, a series of tragic deaths forced the manufacturer to pull the system from the market. Rebreathers remained almost the exclusive province of military divers until 1987, when Stone and his team brought them to cave diving.

Today two different types of rebreathers are being used by the cave-diving community. One is electronic and recycles all the gas; the other is mechanical and vents gas from the system every four out of five breaths. By recycling the gas, rebreathers offer enormous efficiencies over open-circuit scuba. An electronic rebreather can extend a gas supply by a factor of 40 to one, whereas a semiclosed system provides an eight- to 10-fold advantage. Their complexity, however, makes them less reliable than scuba and introduces additional physiological risks. In the event that the system malfunctions, the diver may suffer hypoxia (too little oxygen), hyperoxia (too much oxygen) or hypercapnia (CO_2 buildup, in this case caused by a malfunctioning scrubber), all of which can result in unconsciousness and drowning.

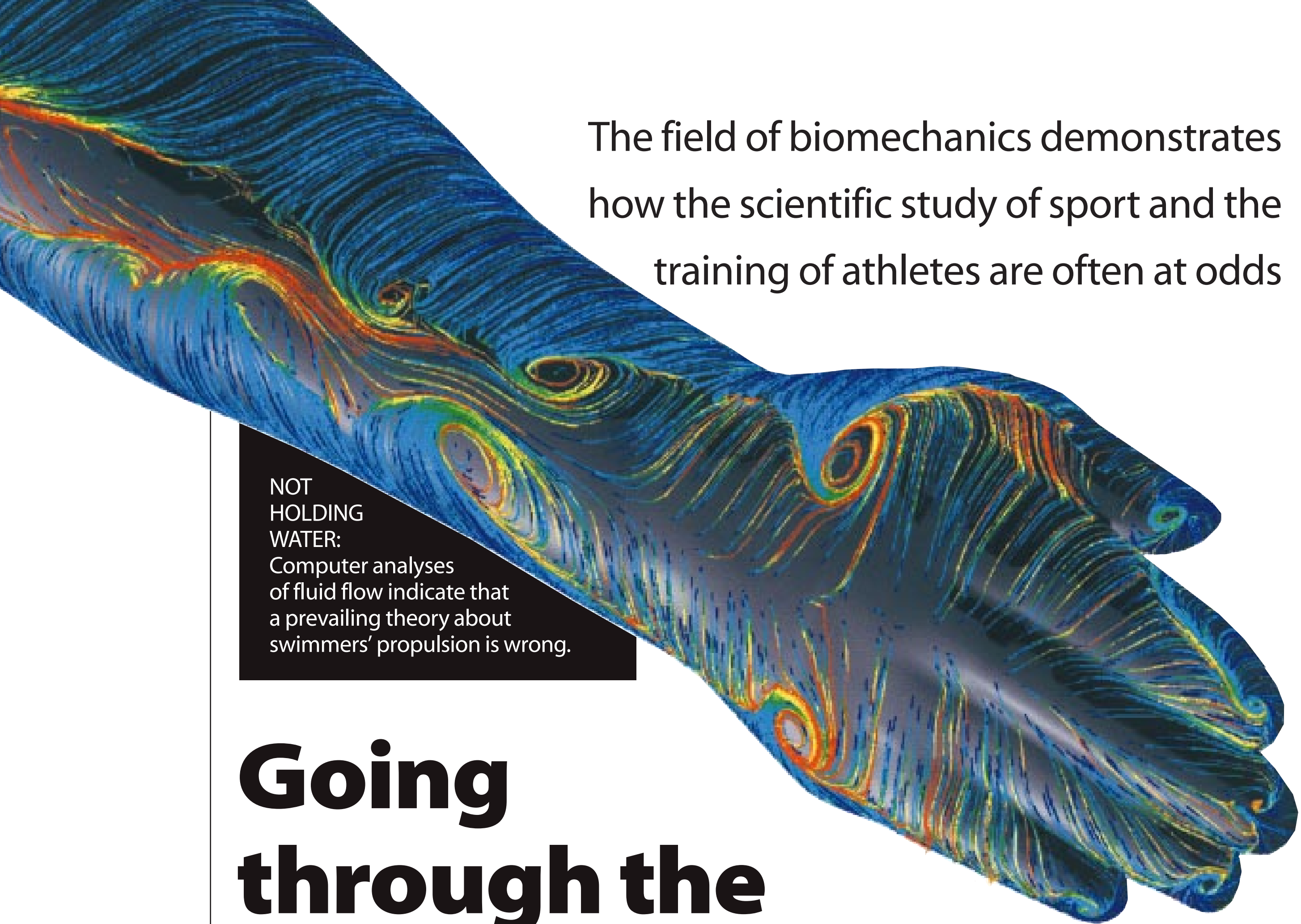
In addition, rebreathers require extensive training and significant predive and postdive maintenance to ensure that they function properly, making the equipment too complex for most divers. But that won't stop well-heeled explorers from plunking down their cash nor hinder the continued development of rebreathers. Because most of the easily accessible sites have been visited, cave exploration is becoming increasingly technology-driven. Future exploration will most likely require further refinements in gas and rebreather technologies. So a sport that is already one of the world's most dangerous exploits will demand even more expertise and daring of its practitioners.

MICHAEL MENDUNO (www.menduno.com) is a freelance writer based in Menlo Park, Calif., who has been diving since 1977. In addition to being cave certified, he was the founder, publisher and editor in chief of *aquaCORPS,* the first magazine devoted to technical diving (1990–1996).

FURTHER INFORMATION

Various cave-diving organizations maintain sites on the Web, including the National Speleological Society's Cave Diving Section (www.caves.org/section/cds/) and the National Association for Cave Diving (www.safecavediving. com/).

The field of biomechanics demonstrates how the scientific study of sport and the training of athletes are often at odds



NOT HOLDING WATER: Computer analyses of fluid flow indicate that a prevailing theory about swimmers' propulsion is wrong.

Going through the Motions

by Delia K. Cabe

A pitcher's windup. A gymnast's dismount. A swimmer's glide. Basic principles of physics govern these movements. Biomechanics, the discipline that studies them, tries to reduce the heroic grace and power of the athlete to its most essential constituents. A medal-winning dash to the finish line is not a triumph of the human spirit but a product of mass times acceleration. Biomechanists are the practitioners of the most fundamental science of sport. If only center of gravity, velocity and acceleration could be deduced with sufficient precision, a winning performance might be engineered from first principles. In such a world, the coach would become more cheerleader than trainer.

This vision follows logically from an understanding of the research endeavors of biomechanics. Paradoxically, these premier scientists of sport would be unlikely to articulate such a grand scheme for their doings. Many biomechanical experts, in fact, are having to fight a defensive rearguard action to justify the relevance of their jobs.

In the real world of coaching elite athletes, biomechanists don't get much respect, despite the 35-year history of the field. Trainers do consider biomechanical analyses, often based on digitized videos of an athlete's performance. For instance, a biomechanist might suggest the best position for a volleyball player to place the arms in relation to the shoulders so that the deltoid and pectoral muscles produce the most force. Still, the biomechanists' recommendations are often relatively minor input in an overall coaching strategy.

NO TIME FOR BOUND VORTICES

Why have scientists schooled in the physics and engineering of athletic movement fallen into such disrepute? To begin with, biomechanical experts are lousy communicators, says Benjamin F. Johnson, director of the biomechanics and ergonomics lab at Georgia State University. The significance of their research is hidden under a blanket of scientific jargon. Explanations of the Magnus effect and bound vortices have yet to prove inspirational to either coaches or their charges. To many coaches, biomechanical analysis smacks of academic esoterica—a set of numerical abstractions di-

BARRY BIXLER

vorced entirely from the intense psychological focus and drive that distinguish select athletes from mere mortals. "[Scientists] measure only things they can measure, and therefore if they can't measure something, in their minds it doesn't exist," says Richard Quick, head coach of the U.S. women's swim team.

Whether superstitious or simply cautious, athletes and coaches do not want to take a gamble with scientific data that suggest changes to a technique that has produced winners again and again. Like any science, biomechanics continues to evolve, and a recommendation to do one thing one year may be completely reversed a few years hence. Swimming provides an ideal example. Theories about the underlying physics—and consequent suggestions on stroke technique derived from the science—have shifted back and forth in a way that exasperates some coaches.

THROWING OUT NEWTON

Until 1969 scientists thought that the propulsion from a swimmer's arm stroke could be explained by Newton's third law. Pulling the arm through the water with a certain force provoked an opposite force of equal intensity, as per Newton, lending the swimmer the necessary forward propulsion. Extrapolating from theory, coaches at the time told athletes to pull their arm straight back in a stroke they thought would elicit the most oomph—the greatest Newtonian countershove—from the viscous medium they travel through.

What remained perplexing, however, was that underwater video taken of the best swimmers showed that their arms did not pull directly back. Instead they traced a curvilinear path as they moved along the lane. James "Doc" Counsilman, a prominent biomechanist and the Indiana University swim coach of Olympic champion Mark Spitz, was originally one of those who had cited Newton's third law in his seminal 1968 work, *The Science of Swimming*. But after having photographed what appeared to be the circular strokes of competitive swimmers with lights attached to their hands in a darkened pool, Counsilman reevaluated his views. How could the body be propelled forward by a Newtonian counterforce if the hands were swerving all over the place?

In a 1971 paper Counsilman presented a new theory, also borrowed from classical physics, that shocked the swimming community. He suggested that Bernoulli's principle, which produces the lift forces that keep an airplane aloft, played a big role in explaining a swimmer's propulsion along a pool lane. Applied to swimming, it means that water travels faster over the knuckles than the palm and that the difference in pressure between the two sides of the hand generates a propulsive force.

For nearly three decades thereafter, Counsilman's views became the received wisdom, and elite swimming coaches taught their students to slice their hand through the water, emphasizing lateral and vertical motions instead of a straight pull back, all maneuvers designed to enhance lift.

The theory seemed enticing and elegant—except that more and more evidence suggests that it's wrong. Critics have said that the surface area of the hands and feet are neither large enough nor curved enough to produce the necessary lift to move a swimmer through the water. More recently, the case against Bernoulli has grown stronger as scientists have developed precise tools for modeling the physical dynamics of the hand and forearm in water.

The U.S. Olympic Committee has provided the funds for Barry Bixler, an aerospace engineer at Honeywell Engines and Systems in Phoenix, to help resolve some of these questions by deploying the computational fluid dynamic modeling tools that he uses in his day job to simulate the way air races through aircraft engines. Bixler, who works with Scott Riewald of USA Swimming, the sport's national governing body, has used the software to show how water behaves on the

UPI/CORBIS-BETTMANN

PATRIARCH: James "Doc" Counsilman (*left*), a seminal figure in swimming biomechanics, coached Olympian Mark Spitz (*right*) and concocted what may be a mistaken theory about how swimmers move through the water.

COURTESY OF SPEEDO

COVERING UP: The use of full-body suits has coincided with a spate of record breaking in swimming.

forearm and hand. The software, which has often been compared to a wind tunnel in a computer, reveals the velocity at which water flows over the limb, pressure changes in the water and the ways these phenomena affect lift and drag forces.

In Bixler's model, the thin boundary layer of water flowing over the surface of a hand and forearm pulled away before it could pass completely around the limb. The computational simulation indicates that the Bernoulli effect does not explain how a swimmer does laps, because the Swiss physicist's mathematics assumed that lift forces would not be produced if air, water or any fluid in the boundary layer separated from the surface of the body around which it flowed.

Astonishingly, these findings take biomechanists back to the original 1960s thesis of Counsilman and others. The hand behaves like Newton's paddle, not Bernoulli's airplane wing. When it puts pressure against water's resistive medium, the hand provokes a counterforce that accounts for the propulsion. Many of those who train swimmers poolside from day to day have witnessed this debate with a growing sense of bafflement. "This has upset some coaches who took a long time accepting the lift theory of propulsion [based on the Bernoulli effect] and who now feel the rug has been pulled out from under them," says Ernest W. Maglischo, a biomechanist and former swimming coach at Arizona State University.

The case is not closed. Some lift still seems to be involved in propulsion. Moreover, Counsilman's original inductive insight, which prompted the shift from Newton to Bernoulli, holds: good swimmers do not stroke straight back but in a somewhat circular pattern, perhaps because they can achieve a longer pull and thus a greater stroke length.

The change in explanation does, however, raise questions about the teaching conventions of the past few decades. Once Counsilman conceived of a swimmer's hand and forearm as a kind of lift-driven wing, instructors taught students to emphasize slice-like strokes that may have led to performance inefficiencies. Maglischo writes in a new version of a swimming textbook he authored that the Bernoulli diversion has caused stroke mechanics to seem "far more complex than they really are. And as a result, techniques for teaching competitive swimming strokes have been needlessly complicated." For his part, Bixler says that if further research confirms these initial findings, a less pronounced sideways motion during the stroke might be ideal. As a good scientist, though, Bixler begs to dither: "Borrowing from a well-known TV show," he says, "that might not be my final answer."

And that may also be just the point. Bixler's research demonstrates how difficult it is for biomechanics to get any hard answers that spring from a foundation of real science. For instance, it takes enormous resources to simulate the complexities of the swimmer's interaction with the water. The computational fluid dynamics analysis provides the most accurate information to date on the dynamics of swimming. But the simulations necessary for precisely modeling the set of variables in Bixler's analysis took six months to run.

One area of athletics in which biomechanics has gained some grudging acceptance is in the design of equipment and sports garb. Although it is a sport relatively free of technological encumbrances, swimming has spawned a recent controversy, not over the effectiveness of teaching a particular technique but over the possibility that a new type of swimsuit is perhaps too good at improving performance. Both Speedo and Adidas have introduced full-body swimsuits made from more advanced materials than the ones with shorter legs and arms worn in the Atlanta Olympics. No one objected back then because they did not perceive the more circumscribed suits as a radical change. The full-length version was harder to ignore and coincided with a spate of record breaking.

SHARKSKIN SUITS

The weave of nylon, Lycra and polyester in the Speedo suit's fabric forms fine ridges that imitate a shark's skin. The manufacturer claims that the suit, which costs between $100 and $300, reduces drag and enhances performance by 3 percent. The operative word is "enhance," and therein lies the controversy. FINA, swimming's international governing body, has approved the high-tech suit for competition. But others, including USA Swimming's national team director, Dennis Pursley, say that it violates FINA guidelines, which preclude any accoutrements that give a competitor an advantage. The Australian Olympic Committee asked the Court of Arbitration for Sport in Switzerland to determine whether the suit breaks the rules, and the court ruled in FINA's favor. Some swimmers think the suit provides an unfair advantage, although other observers say that the suit does nothing more than provide a psychological edge by boosting a swimmer's confidence.

In some athletes' eyes the disservice has to do less with performance enhancement and more with supply. Last spring, Swimming Canada and USA Swimming barred the suits at their Olympic swimming trials because of limited availability. Speedo has announced that it will provide the suit to all swimmers regardless of sponsorship in the Sydney Games, just days after Olympic gold medalist Kieren Perkins of Australia expressed dissatisfaction because the suits were not easy to get. Acceptance of the full-body suits demonstrates that when biomechanists really do make a good case, the kind of academic debates that pit Newton against Bernoulli fade as quickly as the turbulent vortices in a swimmer's wake.

DELIA K. CABE is a science writer who lives in Belmont, Mass.

FURTHER INFORMATION

SPORTSCIENCE, a Web site that includes peer-reviewed research, is available at www.sportsci.org

SWIMMING EVEN FASTER. Ernest W. Maglischo. Mayfield Publishing, 1993.

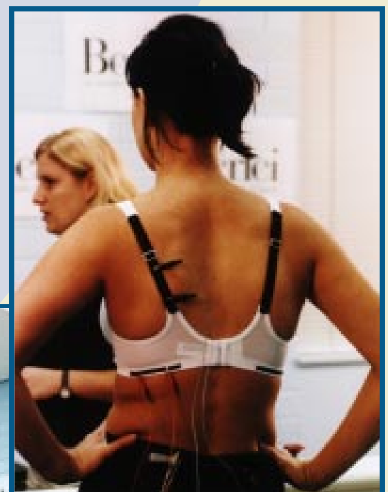
KEEPING ABREAST OF NEW TECHNOLOGY

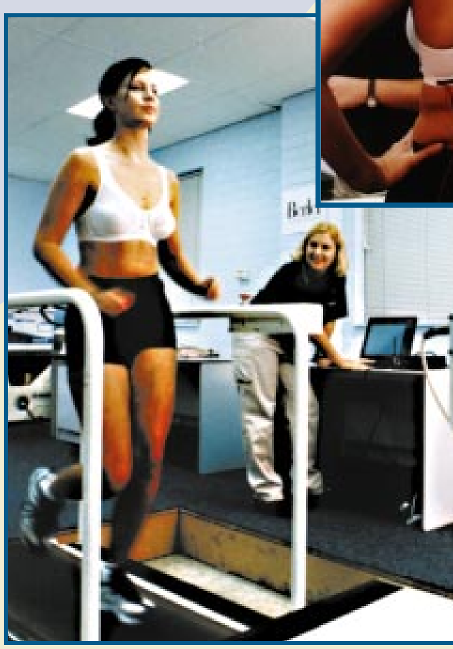
[redacted]

Research by biomechanists and materials scientists at Australia's University of Wollongong may presage the advent of a lingerie department at your local computer store. The researchers have concocted an intelligent sports bra that should make participating in athletics more comfortable for women. A computer microchip will control polymer sensors woven into the Smart Bra, directing the fabric to tighten or relax in response to breast movement. Kelly-Ann Bowles, a doctoral student in biomechanics at the university, is conducting trials to measure breast motion, strap and cup strain, and breast pain across different sizes. "What we need to find is a maximum level of breast motion acceptable and then calculate the strain associated with that," Bowles says.

Bowles and her co-workers, Julie Steele, head of the Biomechanics Research Laboratory, and Gordon Wallace, director of the Intelligent Polymer Research Institute, are hoping that a brainy bra will encourage more women to compete in sports—and prevent the injuries, such as broken clavicles, that are associated with large breasts. Bras as they are designed now, Bowles says, also put pressure on women's shoulders, leading to trough-like strap marks and, possibly, pinched nerves that can affect sensation in their pinkies. The researchers' investigations have just begun, as have their discussions with the Australian bra company Berlei. If the Smart Bra does come to market, which Bowles hopes will happen in the next two years, "software support" will take on a whole new meaning.

—*Naomi Lubick*





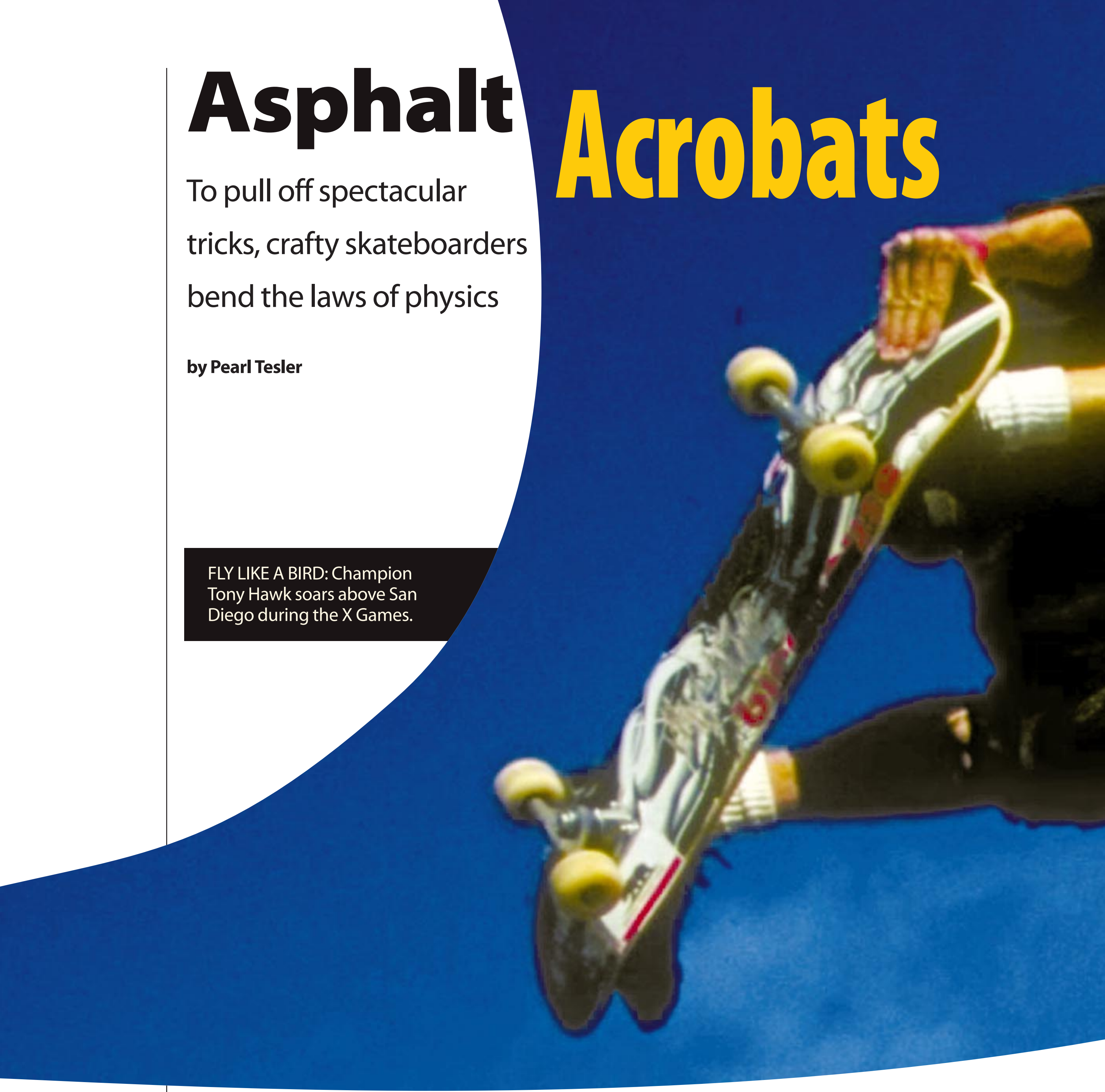
ADJUSTABLE LIFT: Australian researchers test a preliminary mock-up of the Smart Bra, which tightens or relaxes in response to breast movement.

SEAN MAGUIRE *University of Wollongong*

Asphalt Acrobats

To pull off spectacular tricks, crafty skateboarders bend the laws of physics

by Pearl Tesler



FLY LIKE A BIRD: Champion Tony Hawk soars above San Diego during the X Games.

TOM HAUCK *Allsport*

In June 1999 professional skateboarder Tony Hawk made history by performing the impossible. Egged on by a wildly enthusiastic crowd at San Francisco's X Games, he nailed the first recorded "900"—a horizontal midair twist of two and a half revolutions (900 degrees)—high above the huge U-shaped "half-pipe" that launched him toward the California sky.

Starting at the right-hand top of the U, Hawk plunged down inside the half-pipe to gain speed, then vaulted up and out of the opposite wall. Airborne and parallel to the ground, he immediately tucked his body, clutched the skateboard and spun two and a half rotations—finishing quickly enough that he could again extend his legs and push the board back against the left wall of the U before crashing down into the cement pipe's trough. To skateboard fanatics, the 900 was so difficult a maneuver that it seemed to be beyond an invisible barrier. It had eluded Hawk's efforts for 10 long years.

What made the 900 possible? Watching skaters like Hawk soar, twirl and swoop in a sophisticated blur of limbs, the real question seems to be: What makes any of it possible? Executed at top speeds, skateboard tricks can be difficult to follow, let alone understand.

It seems that skaters are defying the laws of physics. But the fact is, they're just cleverly exploiting the forces of nature. Every maneuver a skateboarder makes takes advantage of the fundamental physical principles that govern motion in virtually every sport: speed, momentum, rotation, gravity and good old muscle power. Analyzing skaters' brazen acrobatics unveils the scientific mysteries that allow an ice skater to spin, a diver to twist, a gymnast to tumble and a freestyle skier to catch "big air."

THE OLLIE

Before the 900 was even a glimmer in Tony Hawk's eye, there was the ollie. Invented in the late 1970s by Florida skater Alan "Ollie" Gelfand, the ollie is skateboarding's primordial trick, the foundation on which most other tricks are based. In its simplest form, the ollie is a jump that allows street skaters to skip up onto sidewalks, hop over obstacles and leap across urban chasms.

What amazes onlookers is that the board seems to lift magically with the skater's rising feet throughout the jump. Many people assume that the skateboard is somehow attached to the skater's shoes. It's not. Equally perplexing is that to make the skateboard soar up, a skater first stomps *down* on it. A step-by-step look at this paradoxical trick reveals the secret: skillfully controlled rotation of the skateboard.

The ollie begins explosively. A skater rolling along on flat ground places his front foot in the middle of the board and his rear foot on the tail. He drops into a crouch, which lowers his center of mass (the point where his weight is most concentrated). As the skater approaches the obstacle to be jumped, he throws up his arms and torso, accelerating his body upward before his feet begin to rise. (Starting with a lower center of mass gives the body more distance over which to accelerate before the skater's feet leave the ground. The height of any skateboard jump comes from this upward acceleration; the greater the acceleration, the higher the jump.)

As the skater's body streaks upward in launch, he stomps down hard on the skateboard's tail with his rear foot. The great force on the tail causes the front

THE OLLIE: A skater crouches down as he approaches the abyss, then accelerates himself upward by explosively raising his arms. He stomps his rear foot on the tail of the board while lifting his front foot, causing the board to pivot up. When the board's tail rebounds off the ground, the board pivots in the opposite direction. Once airborne, the skater slides his front foot forward, dragging the nose of the board upward, then levels out the board. If he times these motions just right, his feet and board rise, sail and fall in perfect unison, as if stuck together.

of the board to rear up. The board rotates backward around the rear wheel, nose lifting up into the air like a rising jet plane.

The downward stomp on the tail, however, causes it to strike the ground—hard—a fraction of a second later. The tail then bounces back up. Now the skateboard is fully in the air, rotating forward again; the front tip begins to come down while the back tip moves up. If left to its own devices, the skateboard would eventually flip tail over nose. But the airborne skater uses his feet to control the rotation, sliding his front foot forward to drag the nose of the board upward with his rising leap. Aided by the extra friction of sandpaperlike grip tape on the skateboard's top surface, this dragging motion keeps the skater's front foot in constant contact with the skateboard. Meanwhile the skater lifts his rear foot to get it out of the way of the rising tail. If he times these motions just right, his feet and the board will rise in perfect unison, seemingly stuck together.

At the top of the jump, the skater levels the board with his feet to stop its rotation. Now at their maximum height, skater and skateboard begin to fall together under the influence of gravity. To cushion the impact of landing, the skater drops his arms and bends his knees. In under a second, the ollie is over.

FRONTSIDE 180

After skaters master the ollie, they begin to add aerial maneuvers. One favorite is begun by speeding forward off a curb, or off the top of a short flight of stairs, and launching straight out into the air. Once in midflight, the skater rotates the board and his legs a full 180 degrees before touching down on the ground. Skaters call this a frontside 180; a physics student might call it impossible.

At first glance, the aerial turn seems to violate a basic law of physics, the conservation of angular momentum, which states that if you aren't rotating, the only way to start is with the help of a twisting force—a torque. But a skater already in the air has nothing to push against to create the needed torque. The only force that acts on someone in flight is gravity, and gravity can only make a person fall. It can't make you spin. So how does a skater create rotation out of thin air?

To generate the torque he needs, the skater borrows a trick from the amazing housecat. The lore that cats always land on their feet may not be strictly true, but it's also more than just talk. To right themselves while falling, cats do exactly what the stair-jumping skater must do: rotate while keeping their angular momentum constant at zero. Here's how it works: A cat falling with its back to the ground thrusts its back legs straight out behind its body. It simultaneously tucks its front legs. Extending the rear legs increases their rotational inertia—their tendency to stay straight and resist spinning. This shift of the hind legs creates a small torque that is transmitted through the cat's body. Because the front legs are tucked, their rotational inertia is relatively small; it takes only a small torque to rotate them. The result, very useful for the cat, is that the torque traveling through the cat's torso twists its front legs down toward the ground.

Using its muscles to stop the front legs' rotation when pointing closer toward the ground, the cat generates torque that can travel back through its body and help bring the hind legs around, too. With enough falling time, a cat can ratchet itself around by repeating these opposing twist motions, until both sets of feet are pointed down for the landing.

The torque needed for the frontside 180 is created in much the same way. Once airborne, the skater thrusts his arms out wide. This increases his upper

LUKE OGDEN *(top)*; MICHAEL BURNETT *(bottom)*; BOTH COURTESY OF *THRASHER* MAGAZINE

body's rotational inertia, making it harder to turn. He then throws his outspread arms in one direction, creating torque through the body that twists his legs (and skateboard) in the opposite direction. A nice sweep of the arms can cause a full 180-degree twist of the feet. Because the two rotations cancel each other out, the skater's total angular momentum stays the same—zero—and the law of conservation of momentum remains unbroken.

BIG AIR

Never is a skater's instinctive mastery of physics more apparent, or more necessary, than when she is skating in a big, foreboding half-pipe, a structure sometimes called a vert ramp. Lay a sheet of paper on the table, curl the edges so they point straight up, and you have a rough model of a vert ramp, so called because the topmost sections are perfectly vertical. Actual vert ramps are usually about 12 feet tall.

Once skaters learn how to dive and climb, traversing the trough of the ramp on each pass, they begin to contemplate an alluring daredevil move: getting enough momentum in the downswing to vault them up past the top of the far wall. Once in the air, they rotate a half-turn and skate back down the wall. Good skaters can roll down one side and up the other, return, and then do it again and again, while getting a little air at the top of each ascent.

It may seem that skaters in vert ramps are simply riding back and forth. But—although their parents may disagree—they're really working. Physics holds that when you're at a certain height above the ground—say, atop a vert ramp—you have a store of potential energy proportional to this height. You can convert this energy into kinetic energy, or motion, by rolling down the ramp and collect it back as potential energy when you roll back up the far side. But to make it back up to the top, a skater has to compensate for the energy lost to air resistance and the friction of the wheels on the cement half-pipe by adding energy. And if she wants to rise above the ramp—necessary for an airborne turn—she has to add even more energy. This means work.

On flat ground, the conventional skating method for adding energy is to push off the ground with one foot. But in vert ramps, skaters use a more elegant method called pumping. To pump, a skater crouches down while traversing the flat bottom of the ramp. Then, as she enters the upward curve, called the transition, she straightens her legs and rises. By repeating this motion each time she passes through the transition, a skater gives herself incremental boosts of speed that allow her to rise above the ramp wall.

Paul Doherty, a physicist at the Exploratorium museum in San Francisco, explains that this kind of pumping is identical to the pumping you do to go

FRONTSIDE 180: To rotate the board while in the air, a skater twists his upper and lower body in opposite directions to create torque, just as a falling cat twists to get its legs underneath itself before hitting the ground.

MICHAEL BURNETT (*above*); LUKE OGDEN (*right*); BOTH COURTESY OF *THRASHER* MAGAZINE

BIG AIR: To vault high above a half-pipe, or "vert ramp," skaters use a pumping technique similar to the one children use to soar high on a playground swing.

higher on a playground swing, in which you lift your ankles and feet up and forward as they pass through the bottom of the arc, then drop them at the top of the arc. "When you lift your legs at the bottom, your muscles have to work extra hard against the gravity force and the centrifugal force," Doherty says. "The energy you exert by lifting your legs against these forces makes you go higher and faster." The same principle, of course, applies to skaters in vert ramps, but instead of lifting their legs, they lift their whole bodies. So, if pumping makes skaters go higher, the next natural question is, Just how high can they go?

Skaters know that big air—rising high above the top edge of the ramp—is partly a function of ramp size. The current record holder, Danny Way, rose 16.5 feet out of an exceptionally tall, 18-foot ramp assembled by the DC Shoe Company at an airstrip near the California-Mexico border. Large ramps are more forgiving of the high-flying skater, because their larger transitions ease the shift from vertical to horizontal motion. And because the greater speeds they create mean greater centrifugal force to push against, the large ramps also make pumping even more fruitful. But at some point, the energy added with each pump can't compensate for the energy lost to wind resistance. The upshot? Height records will continue to climb, but each successive inch will come at a steeper price.

900 DEGREES... AND BEYOND?

By now it might be clear how legendary Tony Hawk manages to do the 900—and how stunning the maneuver is. Hawk must create a strong enough pump to launch himself sufficiently high above the vert ramp to have time to spin 900 degrees. And he must find a way to create the necessary catlike torque to twist his body two and a half times.

The truth is that to pull off a megatrick like the 900, Hawk also has to use a bit of catlike sneakiness. The two seconds he is airborne isn't quite enough time to fabricate the required rotation for 900 degrees of spin. Hawk has to leave the ramp already spinning. Then he must parlay this rotational energy into an even faster spin with a technique common to another form of skating—ice skating.

To accomplish their triple lutzes, ice skaters start with a wide sweeping spin, arms and legs extended. In the air, they pull their limbs in. This decreases rotational inertia, causing them to spin faster automatically.

Likewise, before he launches from the top of the ramp, Hawk gives himself a sizable amount of angular momentum. He approaches the top of the ramp with outstretched arms. As he nears the top, he tucks and begins to spin his body, pushing hard on the board to create an angular force. The angular momentum gained in this moment is all he'll have throughout the trick. After he leaves the ramp, he can't get any more.

The moment he is airborne, he speeds up the spin by jutting one outstretched arm high over his head, adding rotational torque. He drops the other arm to hold the skateboard (there's not enough friction between his feet and the board to drag it along during this superfast spin). Placing his arms in line with his body—his axis of rotation—speeds his spin, allowing him to squeeze in two and a half rotations in two seconds. These rotations are an act of faith. Hawk is no longer in control; at best, his control is limited. Turning quickly, body almost parallel to the ground, he twice completely loses sight of the ramp from which he has launched and onto which he must land. Only by throwing his arms wide after the second full spin can he slow his rotation enough to "spot" his landing. As the skateboard touches down, he absorbs his momentum by collapsing into a deep crouch, readying himself for a controlled yet jubilant landing at the bottom.

Hawk had hardly rolled to a stop after performing his miracle 900 when the buzz began: Could he do three full spins, a 1080? In an on-line chat room interview, Hawk unambiguously put the speculation to rest: "I don't have any desire to spin any further." Hawk describes each punishing attempt at the 900 as a potential trip to the hospital. Now 32 years old, he seems happy to leave the 1080 to younger, sprier disciples.

If you ask Jake Phelps, editor of *Thrasher* magazine, the skateboarder's bible, a 1080 is a definite, if delayed, possibility. "Someone may do it," he comments, "but not for a long time." Skateboarding, Phelps continues, is in a state of perpetual evolution, constantly consuming and reinventing itself as new tricks become old hat: "The greatest thing about skating is it changes every day. The first time I saw somebody ollie on the street I was like, 'No way!' But now every kid can get on a board and make an ollie. Today's impossible trick is just cannon fodder for the future."

THE 900: Tony Hawk goes where no skater has gone before, vaulting out of a vert ramp (*from bottom up*) and rotating two and a half times before landing back on the ramp.

PEARL TESLER is a science writer at the Exploratorium museum in San Francisco.

FURTHER INFORMATION

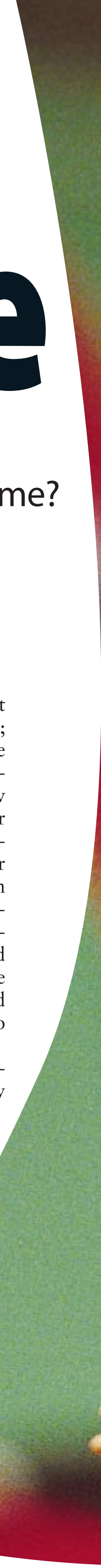
SKATEBOARDING TO THE EXTREME! by Bill Gutman, offers how-to instruction.

News and trick tips can be found on the Web at www.skateboarding.com and in *Thrasher* magazine.

The Athletic Arms Race

Does better equipment heighten competition or ruin the game?

by Mike May



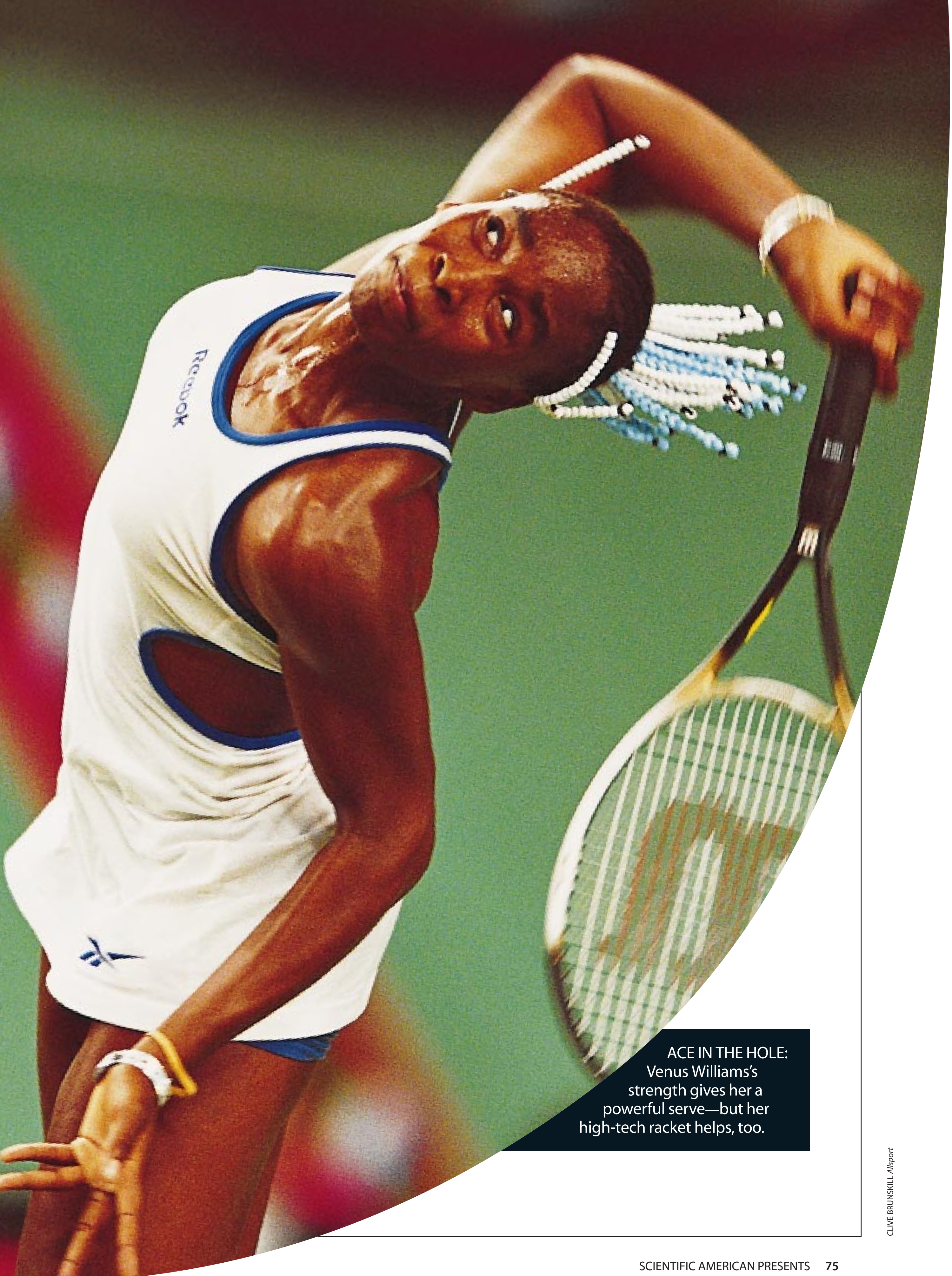
For decades, world records in speed skating were broken by tiny increments, sometimes only one or two hundredths of a second. Suddenly, in 1997, records plummeted by full tenths of a second at a time. Even more startling, virtually unknown skaters were crushing the favorites. The reason: the clap skate. This new piece of equipment carved time off every lap. The skate caused an avalanche of tumbling records at the 1998 Winter Olympics in Nagano, Japan. In the first round of the men's 500 meters, Italian Ermanno Ioriatti set an Olympic record. A few minutes later American Casey FitzRandolph broke Ioriatti's record. Next, Canadian Kevin Overland surpassed FitzRandolph. Finally, Japan's Hiroyasu Shimizu beat Overland. In the men's 5,000 meters, the world record fell three times in less than half an hour.

Spectators could actually hear speed skating change. A traditional skate—a steel blade attached rigidly to a boot's toe and heel—makes a swooshing sound with each stride across the ice. But a passing clap skate creates a rhythmic clatter. The key change is a spring-loaded hinge that connects the blade to the boot's toe. Beneath the heel, the blade is free to swing away from the boot. When a skater's heel begins to lift up at the end of a stroke, the hinge lets the back of the blade stay on the ice until the foot is raised high. The clap sound comes at the very end of the stroke, when the rear part of the blade snaps back into place. By keeping the blade on the ice longer, a skater gets more push for each stroke, propelling him or her faster. The concept of clap skates had been around for nearly a century, but it made its debut among top skaters at Nagano, spurred on by a host of athletes and scientists from the Faculty of Human Movement Sciences at Free University Amsterdam.

Despite the blazing times, the new skates did not suit everyone. Some skaters took to them fairly easily; others felt like babies learning to walk. "The first time you step onto the ice, you almost fall over," FitzRandolph says. Competitors can't simply strap on the new skates and tear through records. In a few cases, lesser skaters who had quietly trained with the new technology before the Nagano Games had an edge over faster rivals who hadn't gotten used to the equipment soon enough to use it during competition. The skate requires a different stroke, one that pushes more forward and from the toe rather than to the side and from the heel. Although FitzRandolph is comfortable in clap skates now, he admits, "I really like the old skates." But no one dreaming of gold can go back to the previous technology.

The clap skate illustrates a fundamental tension between innovation and sport. Competitors continually look for a technological edge, from faster skates to harder-hitting baseball bats. Likewise, manufacturers persistently enhance equipment in a scramble to win more market share. Governing bodies are thrust into the role of negotiators, hoping to preserve a sport's intended challenges in the face of an athletic arms race.

At first glance, technological advancements seem beneficial, because in most sports incremental improvements can distinguish winners from losers. But taken to the limit, better equipment can reduce or even eliminate the role of athletes' abilities, conditioning and cunning. As Nadine Gelberg, who specializes in sports at Harris



ACE IN THE HOLE: Venus Williams's strength gives her a powerful serve—but her high-tech racket helps, too.

CLIVE BRUNSKILL *Allsport*

QUICK CHANGE: At the 1998 Winter Olympics in Nagano, favorites who stayed with a conventional, rigid blade (*top*) were bested by lesser skaters who had switched to the new, spring-loaded clap skate (*bottom*).

Interactive, a market research firm, explains, "Sports are essentially about a challenge, and there's a particular set of skills necessary to meet that challenge. The question is: When does innovation usurp the skills necessary for the challenge?" Tennis could devolve into a serving contest if advanced rackets propelled balls at such blinding speeds that no one could return them. A golf ball designed to self-correct its flight down the fairway would no longer test a golfer's accuracy.

On the other hand, Gelberg points out, technological improvements can widen the participation of youth and women in some sports. And certain advances, such as better running shoes, do indeed simply improve the fair contest between athletes. In essence, sporting equipment should be good but not too good. Technology should not change the basic nature of a game. The real disagreement is over where to draw the line.

OVERGUARDING THE GOAL

The National Hockey League had to draw a few lines recently after controversy over goalie equipment. The NHL hired Dave Dryden, a star goalie from the 1970s, to help. "Over the years," Dryden says, "the focus of goaltenders had changed from wearing equipment to protect themselves to wearing equipment that fills up the net." Some goalies were wearing jerseys so oversized they looked like capes. Did this make it harder for opposing players to score? "Yes, absolutely," Dryden says. "For the player coming in at the goal and trying to find a spot to shoot the puck, there really weren't a lot of spots left."

In 1998 the NHL ruled that a goalie's equipment could protect only the goalie, not the goal. The rules laid down specific limits for a jersey. It can't be wider than nine inches at the wrist, 29 inches at the chest and 30 inches at the hips. From front to back, it must be no more than 14 inches, and length is limited to a maximum of 32 inches. The changes also limit goalie pant legs to a width of 11 inches at the thigh. As for padding, the rules say only that it must be form-fitting; no bumps or ridges can be added to increase size.

Although NHL officials meant to even out the challenge between scoring and defending, the balance might be swinging to the scorers. "The goalies are saying to me, 'Jeez, Dave, the pucks are coming

BONT SKATES (*standard skate*); STEVEN SUTTON *Duomo* (*skater*); CHRIS TROTMAN *Duomo* (*clap skates*) a lot harder now than they used to,' " Dryden relates. The fastest shots now surpass 100 miles per hour. Dryden expects the league to look soon at the construction of hockey sticks to determine whether they launch the puck too hard. Another technology battle might lie just ahead.

THE HAPPY NONHOOKER

Technology really appeared to overshadow an athlete's skill in 1974, when Fred Holmstrom and Daniel Nepela patented a new golf ball. They made the dimples on the poles of the ball shallow, leaving a deeper band of dimples around the equator. If the ball was teed up with the ring of dimples in the vertical plane and then hit, it experienced reduced aerodynamic forces along the undimpled sides, which made it less likely to hook (veer left, for a right-handed golfer) or slice (veer right). The manufacturer, PGA Victor, called the ball the Polara, but the press dubbed it the "happy nonhooker." To be approved for competitive use, golf balls must face Frank Thomas, who runs the U.S. Golf Association's testing facility. Automated driving machines and accomplished golfers hit the Polara and a host of other balls. "The Polara corrected itself in flight," Thomas says. Consequently, the USGA banned it and developed a symmetry standard: a ball must not be made or intentionally modified to have flight properties that differ from those of a spherically symmetrical ball. The ban triggered a series of court battles in which PGA Victor claimed that the USGA and the Golf Ball Manufacturers Association teamed up to inhibit sales of the new ball. In an out-of-court settlement, the USGA paid the manufacturer $1.4 million, but the ball remained banned.

Thomas explains the need for USGA rules: "If you know exactly where the ball is going to go, instead of going to the next tee you might as well go ahead 250 yards to the middle of the fairway, and start from there." Still, he adds, "we don't want to stifle innovation, because if we specified exactly what every piece of equipment had to look like, golf would be boring as all get-out. So we allow people to innovate, but not to the detriment of the challenge that makes golf so attractive."

Today the USGA tests golf balls indoors on a 70-foot range. An automated system tracks a ball's movement once it is struck, which reveals its initial velocity. A computer simulation then determines the ball's lift and drag properties and calculates how the ball would fly. In a recent batch of tests, the USGA banned a dozen balls out of 1,800 because they would go too far.

To develop long-flight balls, manufacturers examine both design and materials. For example, they can alter the shape and size of a ball's dimples, which can reduce the aerodynamic drag on the ball, making it go farther. Some experiments suggest that hexagon-shaped dimples produce less drag than round ones do. Moreover, materials used in golf balls have changed dramatically, from the boxwood used before the 14th century to today's synthetic core and cover. Manufacturers experiment with many materials in search of ones that are bouncy enough to make a ball travel far but also durable enough for the rigors of the game. Yet they know that their balls must pass Thomas's test, so balls cannot always exploit every technological advantage.

SOARING SPEARS

Aerodynamic improvements also altered an ancient event, the javelin throw. The wooden rod hadn't changed much until the early 1950s, when American Dick Held made metal javelins. East German Uwe Hohn was the first to break the 100-meter barrier with Held's creation, throwing 104.8 meters.

Held's javelins had greater surface area, and the center of gravity was moved back toward the thrower, which created considerable lift. But the spears

LONDON LIFE-PORTNOY/HOCKEY HALL OF FAME (*left*); DAVID SANDFORD *Hockey Hall of Fame* (*right*)

SLY FASHION: Over the years, NHL goalies have sported increasingly wider equipment to block more of the goal, as seen by comparing Minnesota's Gump Worsley (*left*, early 1970s) and Buffalo's Dominik Hasek (1990s). In 1998 the league limited jersey size and pad shape.

tended to descend nose-up, often skidding on landing, making it virtually impossible for officials to determine precisely where they hit. Consequently, the International Amateur Athletic Federation instituted a new rule: to be counted, a thrown javelin had to land point-down.

Further complications arose once throwers changed their style. U.S. Olympian Tom Petranoff says, "Everybody thought that throwing a javelin at 30 to 32 degrees was optimum, but when we started throwing them at 25 or 24 degrees, these things went screaming out. I threw a javelin 110 yards. It still blows me away."

Officials decided the new javelins were flying dangerously far. At a Grand Prix final in Rome in 1985, Petranoff threw a javelin that soared to the right and touched down at a winning 92 meters but then bounced and took off again. The projectile shot across the track and speared a board right below the IAAF officials. The next year, the IAAF pushed the allowable center of gravity in a javelin four centimeters forward. Petranoff's throws dropped by 40 feet. The modifications also essentially forced throwers to return to old techniques, in which finesse means less and brute strength means more. Now, Petranoff says, "people with power can get away with murder."

SPAGHETTI, ANYONE?

Technology has also altered the balance of finesse and power in tennis. Anyone who once played the game with a traditional wooden racket and has tried a modern, high-tech version knows what has changed. Today's large, light rackets let even amateurs send the ball over the net more easily and with greater power.

The arms race in tennis began in earnest in 1977, when a double-strung racket, which employed two sets of strings that did not touch, hit the professional circuit. A plastic coating on the strings made them look like spaghetti, so the rackets were dubbed "spaghetti strung." The separated sheets of strings let the ball sit on the racket longer during a stroke, helping a player put considerably more topspin on the ball.

The invention unleashed a string of upsets that year. At the U.S. Open, Michael Fishbach, who was ranked 200th in the world, beat Stan Smith, who was seeded 16th. Georges Goven, a relatively unknown French player, beat the commanding Ilie Nastase at a tournament in Paris. Nastase quickly switched to a spaghetti-strung racket and defeated Guillermo Vilas, ending the latter's 50-match winning streak. Soon after, the International Tennis Federation banned spaghetti stringing.

Radar guns at international competitions have shown that other inno-

No Return

Tennis rackets have gotten larger, tighter and lighter, making serves and passing shots faster. Shown here from left are a wood frame (1948), doubled-up "spaghetti strings" (1977, the year they were banned) and a carbon-fiber frame (1999).

WILSON SPORTING GOODS (*left and right*); ALLSPORT (*center*) vations in rackets and balls—in combination with athletic skills—continue to drive up serving speeds. The composite materials in rackets allow them to be lighter and cover a wider area yet withstand the tension of being tightly strung. The result is a bigger sweet spot for hitting hard, accurate shots and higher-velocity serves. A few pros, notably John McEnroe, have complained that the rackets threaten to transform tennis into a game of blistering serves that only incredible returners like Andre Agassi can handle. The technology improvements that bring more amateurs into the sport might destroy their interest in the professional game if matches turn into strings of one-shot points.

UNFAIR WAY: The Polara golf ball had vanishing dimples at its poles, which reduced a duffer's hook and slice. An ordinary ball (*right*) has uniform dimples all around. The USGA forbade the Polara's use in competition in 1977.

NADINE GELBERG *Harris Interactive (left)*; MIKE NEVEUX *Corbis (right)*

BANNED BATS

For many Americans, one of the most obvious consequences of technology emerged in Little League baseball in the early 1970s, when the ping of aluminum bats started replacing the crack of wood. The metal bats provide an economic advantage because they don't break like wood ones do. But for the players, aluminum bats pack more punch. They are lighter, so a player, especially a child, can swing faster, sending out harder hits. And manufacturers can move an aluminum bat's center of gravity toward the knob, which also increases swing speed. Finally, the ball rebounds better off the aluminum, again adding power to the outgoing sphere. James A. Sherwood, director of the Baseball Research Center at the University of Massachusetts at Lowell, says, "The sad part is, it's like the technology is beginning to control the game more than the players' ability."

Aluminum bats never affected Major League Baseball, where they are banned. But they raised a ruckus in the National Collegiate Athletic Association. To protect fielders, NCAA officials want to prevent aluminum bats from hitting too hard. To do that, they turn to Sherwood. His facility includes a Baum Hitting Machine, in which motors collide a baseball and a bat at computer-controlled speeds. The device then measures the ball's rebound. In the past, an aluminum bat hit a ball about 10 miles an hour faster than a comparable wood bat did. The NCAA ruled recently that an allowable aluminum bat can hit a ball only as fast as a 34-inch, 31-ounce wood bat can. According to Sherwood's results, with a pitch speed of 70 miles an hour and a bat-tip speed of 85 mph, a ball takes off at about 96 mph.

Following suit, other organizations are also instituting similar rule changes. For instance, the National Federation of State High School Associations is developing a rule mandating that a 34-inch wood bat and a 34-inch aluminum bat hit the same. It is apparent, however, that manufacturers and players will continue to seek a technological edge. Perhaps manipulating a bat's center of gravity will create an advantage. "Here it's kind of technology versus technology," Sherwood adds. "I have the machine that can catch it, but they may find a way to circumvent the machine."

LAYING DOWN THE LAW

The athletic arms race involves many factions. Players want better performance. Professional team owners and college recruiters crave improved records to attract more fans and make more money. Manufacturers pursue bigger market share by producing "better" products. It is therefore up to governing bodies to limit technological advances enough to preserve a sport's integrity. The question is how best to do that. Some officials confront advances one by one, writing a new rule to outlaw each specific device. Market researcher Gelberg, however, thinks that rules should protect specific skills. The USGA's symmetry rule is a good example: it outlaws any ball—not just the Polara—that performs in a certain way. Experts such as Sherwood and Dryden are helping baseball and hockey in their pursuits of equally useful rule changes.

If governing bodies take on technology case by case, it will leave them constantly open to new attacks. "The problem with ad hoc design standards is that you're going to get a new design tomorrow that will have the same impact on the game, the same impact on challenge, and it's going to be permitted because that particular design was not banned," Gelberg warns. She says defending skills, rather than limiting individual innovations, is the way to go.

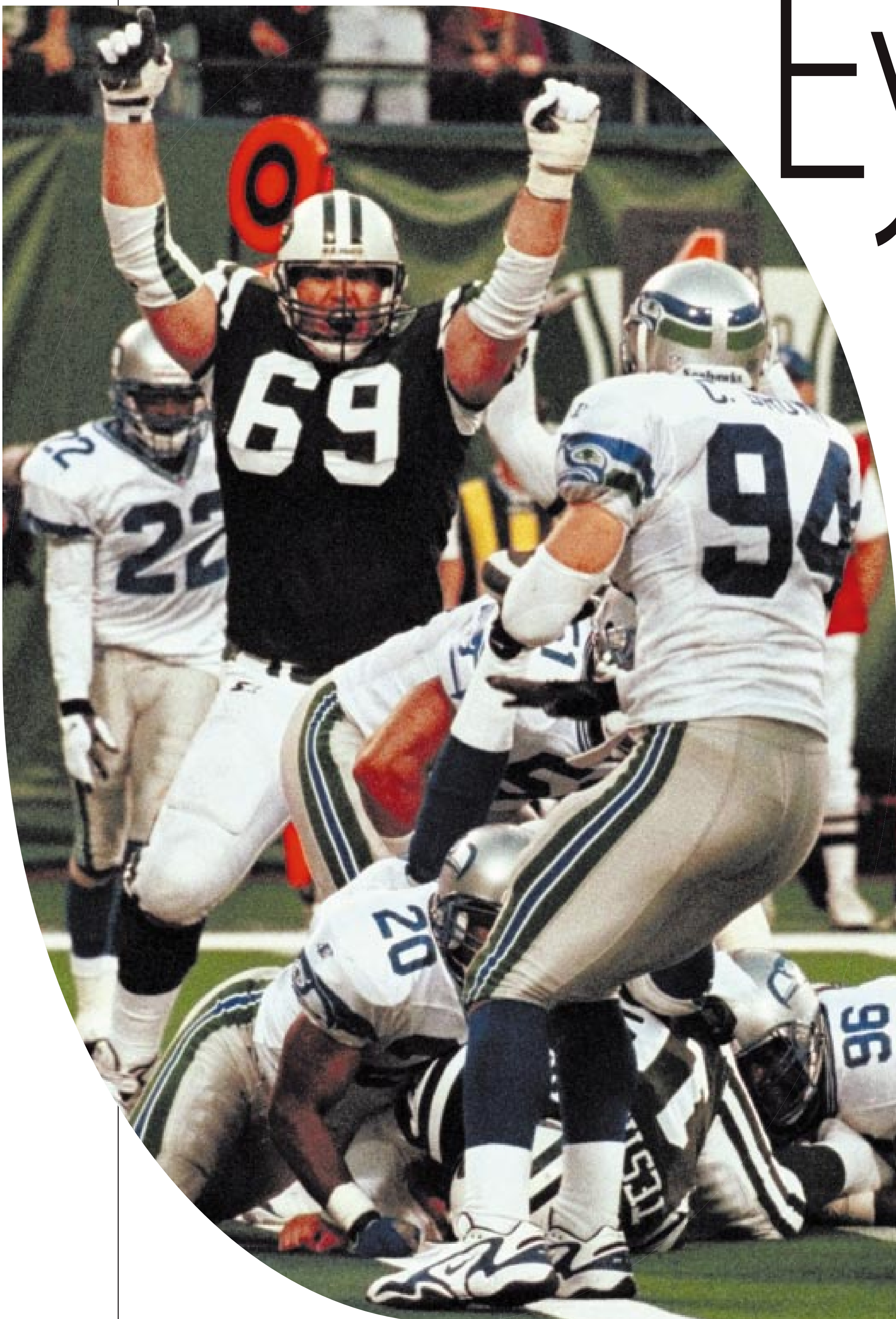
MIKE MAY is a freelance writer based in Clinton, Conn.

FURTHER INFORMATION

THE BIG TECHNOLOGICAL TENNIS UPSET. J. Nadine Gelberg in *American Heritage of Invention and Technology*, Vol. 12, No. 4, pages 56–61; Spring 1997.

CLAPSKATES AT NAGANO: WORLD RECORDS TUMBLE IN SPEED SKATING. T. L. Allinger in *Sportscience News;* March/April 1998. At www.sportsci.org/news/news9803/clapnagano.html

the Unblinking Eye



TOUCHDOWN… NOT: Videotape replay in 1998 showed that a game-winning touchdown by New York Jets quarterback Vinny Testaverde (*on the ground*) was a miscall.

Technologies that can see better than humans encounter a mixed reception on the playing field

by Bruce Schechter

Fans of sports and magic know that the hand is often quicker than the eye. Just ask Vinny Testaverde. In 1998 Testaverde, the New York Jets' quarterback, had brought his team to within striking distance of beating the Seattle Seahawks in one of the final games of the season. On fourth down, with 20 seconds left in the game and the ball on the Seahawks' five-yard line, the Jets needed a touchdown for victory. Testaverde carried those last five yards himself and was tackled just as he dove across the goal line. Head linesman Earnie Frantz signaled a touchdown, and Jets fans went wild.

It was a classic football moment—except for one detail. The referee was wrong. The videotape replay and newspaper photographs clearly showed that Testaverde went down before he ever crossed the goal line. For football fans it was the final straw. The Jets' unearned victory was the most egregious illustration of the occasional and unavoidable fallibility of human officials. Earlier that season the Buffalo Bills had been the victims of a couple of botched calls in a loss to the New England Patriots—and their owner was fined $50,000 for complaining. Officials had even managed to foul up a coin toss in a game on Thanksgiving. These highly publicized mistakes finally forced league officials and team owners to reinstitute the use of instant replays by officials, something they had been resisting for seven years.

Sports fans and athletes have always been critical, to say the least, of the impartiality and visual acuity of the umpires, referees, linesmen and others who are charged with making sure the rules of sport are observed. Until the 1960s, differences of opinion were simply that—fans and officials had to agree to disagree. Whether a pitch was over the plate or a foot was over the line was a fact writ in water. Then Roone Arledge of ABC Sports began to experiment with new video technology and radically reshaped the experience of viewing sports. He liberated sports from time.

Arledge employed cameras to isolate and analyze, putting them in places they had never been before: on the sidelines, in the end zone, on cranes and even underwater. He also used the ability of videotape to freeze a moment or play it back in slow motion, revealing in unprecedented detail "the thrill of victory and the agony of defeat." This technology has its roots in experiments conducted almost a century earlier by English photographer Eadweard Muybridge. Muybridge had used a series of still cameras to capture the gait of a horse and to resolve the controversy in racing circles over whether all four feet of a galloping horse are ever simultaneously off the ground (they are). Arledge's instant replays cleared up one question—referees do indeed make mistakes—but also triggered an endless string of squabbles over disputed plays.

GOING BACK TO THE VIDEOTAPE

In 1986 the National Football League gave in to the increasing pressure from fans armed with proof of the fallibility of referees and began to use instant replay to help in disputed plays. Unfortunately, videotape technology was cumbersome and slow—it takes time to rewind and cue up a tape—and the camera angles sometimes made the replays hard to interpret. In 1991 a replay took over three minutes to review. In that season, 570 plays were examined, and 90 calls were reversed. League officials would later admit that of these at least nine were reversed incorrectly. It did not seem to the owners worth the trouble, time and expense. Besides, they reasoned, in the course of a season, mistakes should even out. So the NFL discontinued playbacks.

By 1998 it was evident that sometimes things do not even out. After the season of Testaverde's phantom touchdown, the owners voted to reinstate instant replay, an experiment that continues into the current season. In the intervening years, technology had caught up, making the process faster and easier to manage. Video could now be stored in computer memory, so no time was lost in rewinding. Cameras had gotten sharper. Still, replays took about two and a half minutes to review, so an elaborate set of rules was concocted to limit them: each team could demand only two replay challenges during a game (except in the final two minutes, when replays could be requested only by a "replay official"). If the replay showed that the field officials had made the right call, the challenging team would lose a time-out. So far the system has been judged to work well enough that it has been reinstituted for the 2000 season. The NFL is also considering other gad-

BILL KOSTROUN *AP Photo*

gets, such as the Scanz Scannor, a palm-size wireless device that can download and display video directly to those on the field, allowing the field-level officials instant access to replays.

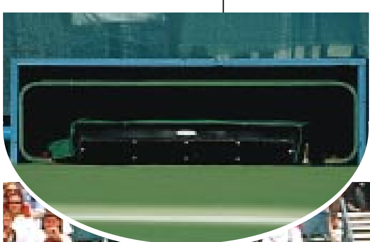
Such technologies will undoubtedly change the way football and other sports are played. Taken to the extreme, they raise the specter of a future without human judgment calls. Although it is easy to imagine that technology will make such a future possible, it seems improbable that sports fans would entertain such an abrupt break with tradition. Still, the fallibility of human arbiters will very likely preserve a place for digital video cameras and computers. Many will welcome the veneer of scientific objectivity that technology brings to sports, but others will insist that this objectivity is an illusion. Just as juries may continue to doubt DNA evidence, sports officials will question the interpretation of replays.

As Cincinnati Bengals president Mike Brown said of football's instant replay, "It still has to be operated by people. [When] you get into decisions made by people, that can go awry." And technology can go awry as well. To err is human, it seems. When a machine makes an error, forgiveness is not only divine, it is nearly impossible. Nowhere is this better illustrated than in the sport of tennis.

When a tennis ball served by Pete Sampras or another top pro hits the court, it is traveling at approximately 100 miles an hour. The ball will stay in contact with the court for about four milliseconds before bouncing off at about 60 miles an hour. All this is taken in by an official who must render a decision. With action so fast, professional tennis matches employ as many as 11 officials to monitor the players, watch the boundaries and the net, and keep score. Using technology to replace some of these officials has most likely been motivated more by economics than by a desire for greater accuracy.

In 1979 a device known as Cyclops was introduced at Wimbledon to monitor the service line and to decide if serves are in or out. The system resembles a burglar alarm. Beams of infrared light are directed just beyond the line. When the ball interrupts the beam—as it must if the serve is long by a small margin—an alarm goes off. For the most part the system works well, but it does have blind spots, which have angered some already temperamental players. Balls that are hit very far out never cross Cyclops's glare and can therefore be judged in. More troubling, the carpet on indoor courts can shift and expand as the day heats up and the players run and slide. This means that whereas Cyclops's beams are unmoved, the court lines can shift by an inch or two, so a ball that the system judges in is actually out (or vice versa). But from the player's point of view perhaps the worst thing about Cyclops is that it just sits there, beeping imperturbably. They would agree with Boris Becker, who once remarked, "I would prefer linesmen doing the job, because I cannot talk to the Cyclops."

CYCLOPS: The infrared sensor monitors the service line of a tennis court.



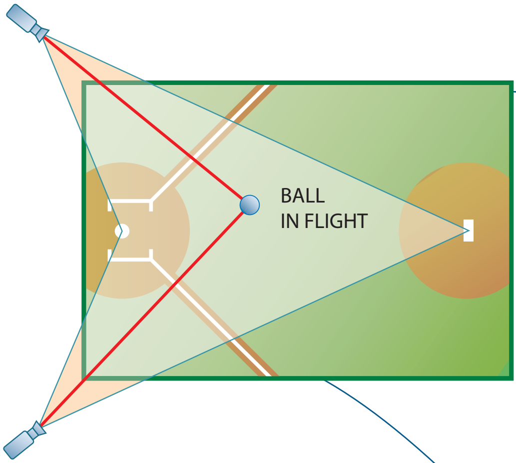
STEVEN SUTTON *Duomo* (top); ART SEITZ *Liaison Agency* (bottom)

For better or worse, Cyclops seems to be here to stay, if for no other reason than that electronic officials are cheaper than humans. Attempts to eliminate the other linesmen have been less successful. One system, invented by an Australian company, involved mixing magnetic particles in with the rubber of the tennis ball. Wires embedded in the court sense the passing of these metallized balls and determine their position. Unfortunately, at some of its first outings the device, known as TEL (Tennis Electronic Lines), malfunctioned and emitted random beeps, which was too much for already oversensitive players to bear. TEL technology is still not a part of the professional tennis circuit.

KEEP THE UMPIRES

In general, tennis fans are fairly forgiving, preferring to leave tantrums over questionable decisions to players. Baseball fans exhibit no such restraint. Scorn for umpires is almost as much a part of baseball as hot dogs or the seventh-inning stretch. A pitch takes about half a second to travel from the pitcher's fingers to the catcher's glove, so it is not surprising that umpires occasionally confuse balls and strikes. What is surprising is that although the technology exists to capture the trajectory of the ball in flight and to render an inhumanly accurate verdict on exactly where it crossed the plate, nobody is clamoring to replace or even supplement human umpires with computers. Not yet.

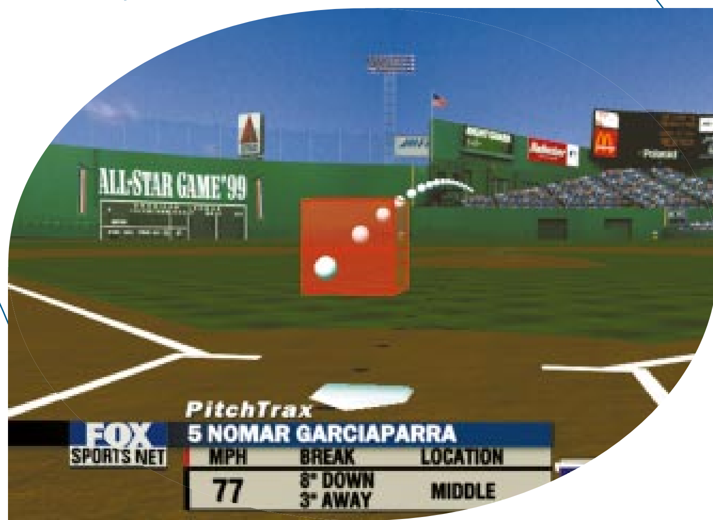
The system in question, which is marketed under the name SuperVision, was first introduced in the early 1990s by QuesTec, a small company in Deer Park, N.Y. Two cameras, one located on the first-base line, the other on the third-base line, follow the pitch. The cameras are fast enough to take 16 pictures of the ball along the way. A computer program isolates the ball and uses triangulation to locate its position at each of the 16 points to within an inch. "We are working on bringing that down to a half an inch," says QuesTec's Mike Russo. Using these positions, the computer constructs a three-dimensional graphic of the tra-



In or Out?

[redacted]

SuperVision uses triangulation (*left*) from video camera inputs along the path of flight to simulate whether a pitch to Boston slugger Nomar Garciaparra is a ball or a strike (*below*).



jectory that can be rotated and examined from any angle. SuperVision convinced any remaining skeptics that a curveball really does curve.

Baseball's adoption of the SuperVision system has been slow. As with any new technology, the first versions were expensive and balky. In 1996, for example, MSG Network in New York City gave SuperVision a spin. The commentators were impressed by its ability to distinguish curve from slider but were not equally wowed by its sense of pace. During one game, it declared that a ball that had left the pitcher's hand at 85 miles an hour arrived at the catcher's glove at the same speed. MSG announcer Jim Kaat turned to his producer and said, "I can't do this. A ball can't do that."

Russo claims that such problems are a thing of the past, eliminated by better software and hardware and by better-trained operators. Televised baseball games continue to make use of the technology. Still, this hidebound professional sport probably won't soon adopt SuperVision or any other system that replaces the umpires who call balls and strikes. Sport is about tradition as much as it is about competition. The reams of statistics so cherished by baseball fans testify to the powerful ties the game has to the past. Comparing today's players to the greats of seasons gone by adds a vital richness to a fan's appreciation. How could a perfect game pitched by David Wells and called by a human umpire ever truly be compared with the accomplishment of some future hurler whose strike zone was circumscribed by a machine? When a catcher fools the umpire into calling an outside pitch a strike, he is being no more dishonest than a runner stealing a base—a certain amount of guile is built into the game. Fooling a computer is not as easy, which makes it unlikely that one will be seen on the field anytime soon.

Off the field, however, technologies like SuperVision are quickly becoming part of the fan's experience of sports. "Everything we do in terms of technology is to embellish the broadcast of the game in the form of storytelling," says Arthur Smith, executive vice president of programming and production for Fox Sports Networks. Smith uses SuperVision, along with technologies such as robotic cameras and telestrators, which allow commentators to draw directly on the screen, to enhance the coverage of a game. "With us it's always about trying to make the game more interesting. It's not how sophisticated a technology is, it's how you use it."

The designers of new arenas and stadiums are beginning to pay as much attention to data lines as to sight lines. Baseball fans sitting in a few hundred expensive seats at Tropicana Field, home of the Tampa Bay Devil Rays, or at Qualcomm Stadium, where the San Diego Padres play, can take advantage of ChoiceSeats, a computer system that floods them with information on the game.

Each ChoiceSeat is equipped with flat-panel touch screens from which computer-literate fans can call up instant replays from half a dozen camera angles or peruse player statistics. They can order food from the snack bar, play computer games or even go shopping for merchandise on the Internet. The game on the field just a few feet away could become little more than a distant, bright, three-dimensional display. But if we are lucky, the computer won't interfere with the pure enjoyment of watching the game, nor will it change the way baseball is played. So, for the immediate future, the umpire will remain a bum.

BRUCE SCHECHTER is a freelance science writer and book author based in New York City.

FURTHER INFORMATION

An explanation of how SuperVision works can be found at www.questec.com on the World Wide Web.

COURTESY OF QUESTEC.COM

Out of This World

Forget Sydney. The wildest Olympic sports could be played on the moon, Mars or the asteroid nearest you

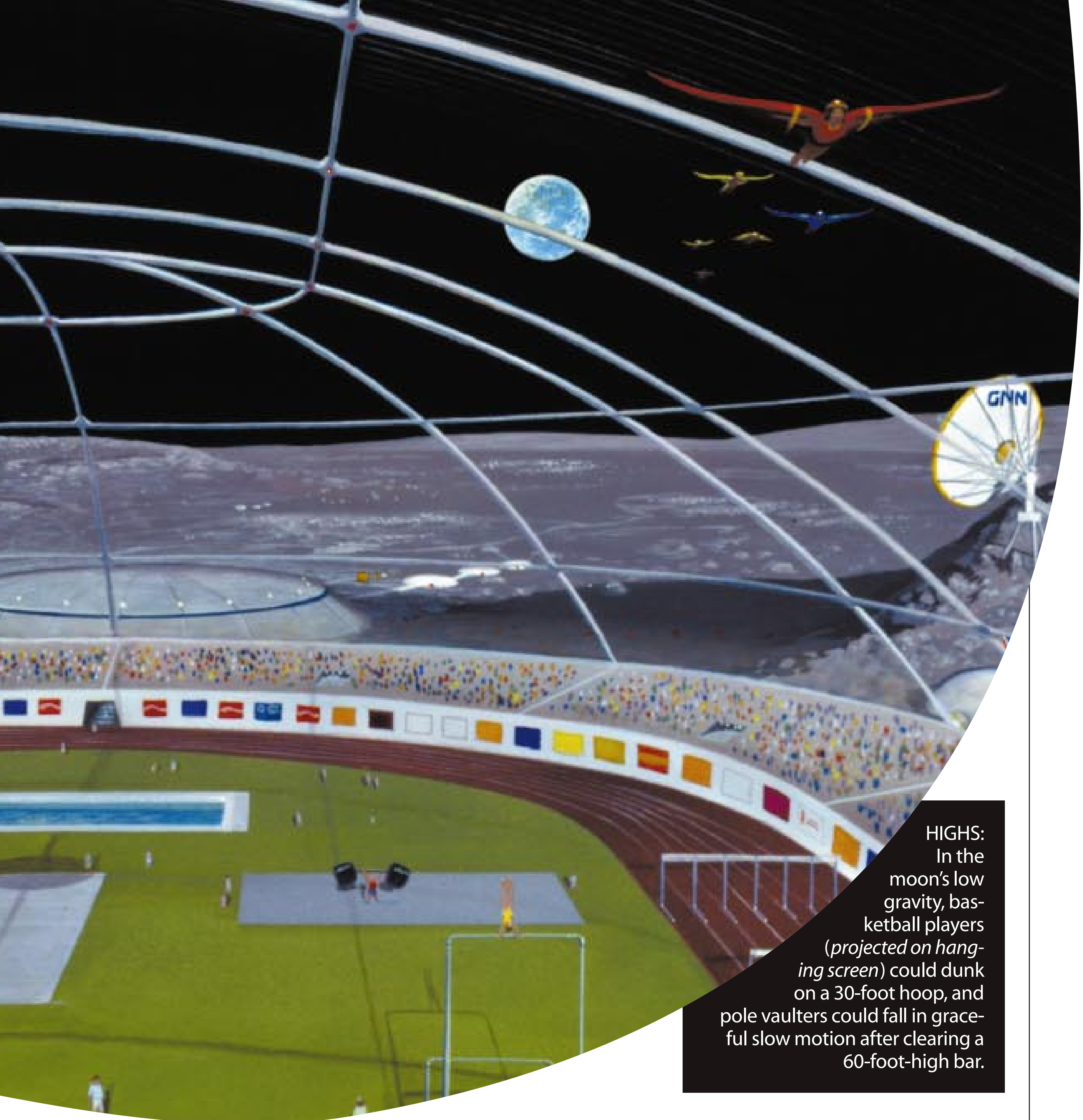
by Ben Bova

The era of extraterrestrial sports began in February 1971, when *Apollo 14* astronauts Alan Shepard and Edgar Mitchell finished the second of their two moon walks in the Fra Mauro highlands. Shepard attached the head of a golf club (a six iron) to the handle of a sampling tool and swatted two golf balls. Swinging with only one hand because of his space suit's stiffness, Shepard topped the first ball; it rolled a few yards into a small crater. His second shot was better. "Miles and miles and miles!" Shepard exclaimed. Later he estimated that the ball flew for some 15 seconds and traveled about 200 yards.

Shepard's brief foray on the lunar links illustrates both the good and the bad of extraterrestrial athletics. The good news is that the alien environment can enhance athletic performance. The bad news is that the alien environment can diminish athletic performance.

Low gravity and lesser air pressure can allow humans to drive golf balls farther, hurl shot puts longer, lift greater masses and leap higher than their muscles let them do on Earth. But the human body must also be protected from the harsh radiation and lack of at-

ALL ILLUSTRATIONS BY PAT RAWLINGS/SAIC



HIGHS: In the moon's low gravity, basketball players (*projected on hanging screen*) could dunk on a 30-foot hoop, and pole vaulters could fall in graceful slow motion after clearing a 60-foot-high bar.

mosphere on extraterrestrial worlds. A space suit must overcome the fundamental problem of maintaining at least several pounds of pressure per square inch on its inside while facing essentially zero pressure in the vacuum of space on its outside. Mismatched in this way, fabric suits balloon so much that they make it difficult for people to move their arms, legs and fingers. Harder suits of metal or stiff composite-plastic shells limit bending at the joints. Gloves that enable fine finger motions are a particular problem. And oh yes, space-worthy athletes need oxygen to breathe.

Given the limitations, sports around the solar system will most likely fall into two major categories: games played in enclosed spaces, such as orbiting space stations or underground habitats, and games played on the surfaces of alien worlds, in protective gear. Which leaves plenty of possibility for creativity and competition. The basic psyche of athletes—the desire to push the limits of body, mind, gear and environment—fuels the imagination to conjure up all kinds of fantastic new athletic challenges.

MOON FLYING

Athletes headed for the moon or beyond might warm up their competitive juices with some friendly gymnastics in the near-zero gravity of orbit. The living and working areas of the National Aeronautics and Space Administration's space shuttle are cramped, but for those with good muscle control there's room for some weightless spins, somersaults and twists.

HANG TIME: Muscle power alone would be enough to propel human fliers in lunar races of speed or endurance.

Once on the moon, our stellar stars would probably head right indoors. The surface of the moon is quite inhospitable. Airless, it is drenched with hard radiation from the sun and stars and is peppered with incoming meteoric dust. Surface temperatures can range from a boiling 270 degrees Fahrenheit in sunlight to a stiff –240 degrees F in darkness. It is possible to encounter a temperature swing of more than 400 degrees F merely by stepping from sunshine to shadow—a bit more of a shock than jumping into a "cold" lake on Earth.

A viable lunar base would be built mostly underground to protect its inhabitants. The interior areas of the base would be filled with a breathable mixture of oxygen and nitrogen, perhaps at nearly full Earth pressure. The athletic advantage would come from the gravity felt in the base, the same as that found anywhere else on the moon: approximately one sixth of terrestrial gravity. An object weighing 100 pounds on Earth would weigh only 17 pounds on the moon. Weight lifters could press many times their own Earthly weight, although they'd have to hang on real tight once they started pushing hundreds of pounds over their heads; stopping the momentum of the massive objects could be a greater test than lifting them.

More interesting would be the indoor flying event. It is feasible to fly on the moon using nothing more than ordinary human muscle power. In an enclosed space filled with air, under the low lunar gravity, a person's Earth-formed muscles are strong enough to lift him or her off the floor to fly, once the person is fitted with a proper set of wings.

Lunar flying would be somewhat like hang gliding, except that someone in decent aerobic shape could actually fly, not merely glide. Of course, fliers would need a large enclosed space in which to move and would sport lightweight wings on their arms. The wings would probably be made of thin plastic, braced with struts of magnesium, and could be manufactured at the lunar base, with all the necessary raw materials retrieved from the moon's surface. Once outfitted, a person could take off, climb, soar and even do aerobatics in the gentle gravity.

With the discovery of significant ice deposits at the lunar poles, it should also be possible to construct at least one swimming pool at the lunar base. It would be built in a separate enclosure, with an efficient water recycling system, and sealed to prevent water loss through evaporation. The water could be purified with oxygen produced from the lunar rocks rather than with chlorine. Although swimming offers good exercise and the psychological benefits of recreation, lunar athletes—and tourist visitors—would be attracted to the high-dive platforms. In the low gravity, platforms could be placed 30, 60, even 90 feet high. Dives would be spectacular; the low gravity means that divers would fall in graceful slow motion—a velocity of less than six feet per second, rather than Earth's 32. Divers would have a seeming eternity to complete numerous somersaults, pikes, gainers and swans before their ultrasoft landing in the water.

Court games on the moon would require much larger playing surfaces than those on Earth do. In lunar basketball, the hoops would be placed some 30 feet above the floor, and the court would be enclosed in clear plastic so that players could literally climb the walls! The ball would arc through the air in dreamy slow motion, yet the competitors would run just as fast as on Earth and jump many times higher. Champion teams would be defined by their ability to execute the slow break and the ceiling drop dunk.

LUNAR LINKS

Shepard's 1971 golf shots demonstrated the difficulty of trying athletic activities in a space suit. If a Lunar Olympic Games took place on the surface, however, there would have to be regulations that took into account the difficulties of running, throwing and lifting while enclosed in a bulky, stiff suit.

Running and walking are quite different on the moon than on Earth. The Apollo astronauts found that their muscles tended to bounce them up off the ground when they tried to take a normal step. Running turned into a series of gliding hops. A foot race would look more like a potato-sack race at a county fair, with the contestants hopping along the course.

Lunar athletic fields would have to be carefully prepared. The ground is rugged and difficult to traverse, littered with stones and boulders and pitted with craters ranging from the size of finger pokes to depressions that could swallow a school bus. Moreover, athletic competitions on the lunar surface would have to be shorter because of the radiation that constantly rains down. On Earth the average person is exposed to about 200 millirads of radiation per year, from natural and man-made sources. On the moon's surface the dose is thousands of times higher. Space suits would provide some protection, but surface activities would need to be strictly limited, for safety reasons.

Despite Shepard's enthusiasm, then, golf on lunar links poses numerous challenges. A decent duffer with a decent suit might hit a ball 500 yards with a driver. Given the need to speed the game to reduce exposure, players might be limited to a pitching wedge and putter to shorten play, or they might drive around the course in updated lunar rover carts. A brightly colored ball would be easier to find amid the rock-strewn landscape. There would be no dearth of sand traps; most of the lunar surface is covered with a powdery residue of micrometeorite dust with the approximate consistency of beach sand.

WHERE NO ONE HAS GONE BEFORE

The quality of the lunar surface suggests another, noncompetitive surface activity for lunar residents and visitors: a First Footprints Club (a concept originated by Hal Clement in his 1974 story "Mistaken for Granted"). Moon walkers could leave their footprints—or rather, boot prints—where literally "no one has gone before." Astronauts left boot prints wherever they walked—prints that will last millions of years in the silent, weatherless vacuum of the moon. A club member would find a spot that had not yet been disturbed, leave his or her boot prints there and spray them with a quick-setting clear plastic to protect them against newcomers. The site could be registered with the club, and the individual could receive a certificate bearing the lunar latitude and longitude of the prints.

Mountain climbing could be another sport. Major lunar craters are ringed with significant mountains. The prominent crater Alphonsus has crests that average more than 10,000 feet. In the lunar south pole region, several peaks are higher than Everest. But despite the light gravity, mountain climbing would be difficult and dangerous. Although most lunar mountains are neither as steep nor as rugged as the Alps, Rockies or Himalayas, their surfaces have been smoothed by billions of years of "sandpapering" by the constant infall of meteoric dust. Their slopes would be slick, perhaps even glassy, making lunar mountain climbing more like terrestrial ice climbing.

The tallest peaks in the solar system are on Mars. The Red Planet is home to several ancient shield

SUNJAMMING

[redacted]

Interplanetary space itself might become the arena for the grandest yachting race. In Earth's vicinity, photons streaming from the sun exert a minuscule but real pressure, enough to accelerate a sail with a thrust of roughly 2.25×10^{-6} pound per square yard of sail. To get any reasonable push, solar sails would have to be of enormous size. The bigger the sail, though, the heavier it becomes, and the more difficult to accelerate. Sails would need to be no thicker than one ten-thousandth of an inch. Engineers believe that a plastic such as Kapton, coated with aluminum to reflect sunlight, could be this thin.

Sunjammer races would be majestic affairs, though painfully slow ones at their outset. It would take at least two days for a sail of 2.152 million square feet (a square with sides of more than a quarter of a mile) to go from an orbit around Earth to escape velocity, but once that speed had been achieved, the sailcraft could reach lunar orbit just as quickly as the Apollo spacecraft did: in roughly three days. In fact, once heading for the moon, sailors would make slightly better time than the Apollo astronauts did, because the sailcraft would be accelerating all the way (albeit slowly), whereas the Apollo vehicles coasted once their rocket engines burned out.

Earth-to-moon yacht races might be arranged when there are facilities on the moon to welcome the winner—and shuttles to rescue sailors in trouble. Sunjammer races would be leisurely, to say the least, but the news media would cover them the way they now cover the America's Cup seafaring races, which take many days to conclude. The world's television screens would show the stately racing yachts, gleaming sails unfurled against the black of deep space. They might appear to be motionless against the background of stars, but each second they would be pushed by the force of sunlight toward their distant goal. —*B.B.*

NO LIFT LINES: Skiers on Mars could enjoy a long, screaming run down the dry ice slopes of Olympus Mons, the tallest peak in the solar system at 88,500 feet.

volcanoes—similar to Mauna Loa and other Hawaiian volcanoes but much larger. The biggest is the aptly named Olympus Mons, three times higher than Everest. Its mighty lava flows cover an area the size of Washington State.

Shield volcanoes tend to have gentle slopes, and Olympus Mons's gradient is only a few degrees. Climbing it, even in space suits, should be relatively easy. Of course, the climbers would need to carry air to breathe, because the Martian atmosphere is as thin as the high stratosphere of Earth and composed almost entirely of carbon dioxide.

Mars is also extremely cold and dry. Although the ground temperature at the Martian equator in midsummer might rise to 70 degrees F, the temperature at nose level—a mere five feet higher—would be zero degrees F, because the thin Martian atmosphere retains virtually no heat. At night the temperature plunges below –100 degrees F.

Temperatures at the top of Olympus Mons's 88,500-foot peak regularly get cold enough to freeze out the carbon dioxide in the atmosphere. As a result, the peak can be covered with a thin layer of dry ice. This would make the going even more treacherous for climbers. When dry ice thaws, it does not melt. It sublimes, going directly from its solid state to gaseous carbon dioxide, with no liquid state in between. Although dry ice is not as slippery as water ice, the pressure of a human body's weight on a thin coating of dry ice might be enough to make the dry ice sublime into a thin coating of carbon dioxide gas. Gas bearings are used in machinery because they are almost friction-free. A mountain climber stepping onto a thin coating of dry ice might suddenly find herself slipping helplessly.

Skiers would love it, though. The thrill of sliding down the flank of the highest mountain in the solar system might be well-nigh irresistible to ski buffs, despite the cost and risks of reaching Mars and getting to the top of Olympus Mons.

Surface sports on Mars would be a modified version of lunar surface sports. The gravity is greater, roughly twice that of the moon and one third that of Earth. Although Mars has an atmosphere, it is much too thin to protect people against the solar system's hard radiation. Mars also lacks a magnetic field strong enough to deflect charged particles pouring in from space. So sporting events there would be limited in duration as well.

Mars is the most Earth-like planet in the solar system. The environments on Mercury and Venus are extremely hostile. And Jupiter, Saturn, Uranus and Neptune are gas giants; if there is any solid surface on these planets, it is buried beneath thousands of miles of atmospheric gases—mostly hydrogen, helium, methane and ammonia. Pluto, the smallest and farthest planet, is so cold that nitrogen condenses out of its atmosphere and falls as snow. None of these worlds seems a likely place for sports.

BLOODBOILING: THE ULTIMATE DAREDEVIL SPORT

[redacted]

The human body cannot survive in the hard vacuum of space for more than a few moments. When exposed to vacuum, the blood begins to boil, as do the fluids in the eyeballs. Gases in the lungs and other organs erupt violently. But this does not happen immediately; a person suddenly exposed to vacuum may have nearly half a minute before his body is irreversibly damaged. This could lead to the "sport" of vacuum breathing, or bloodboiling: daredevils deliberately exposing themselves to vacuum, intent on setting a new record. As in "chicken" games on Earth, the casualty rate would be high, and such activities would be strictly prohibited—making them all the more tempting for rash tourists and workers bored with living in sealed space habitats. The rush would be greater than that of any Earth-bound "extreme" sport. *—B.B.*

A STONE'S THROW: Athletes on nearby asteroids would compete to hurl boulders into the farthest orbit.

If habitats are placed in orbit around them, however, the same opportunities for microgravitational athletics that are available in Earth orbit would be possible. Jupiter's four Galilean moons range in size from just smaller than our own moon (Europa) to slightly larger than Mercury (Ganymede). Saturn's largest moon, Titan, is bigger than the planet Mercury and covered with a thick, smoggy atmosphere of hydrocarbons. Habitats similar to those built on the moon would be needed to live on these distant satellites, and similar indoor sports might be accomplished on them. Surface activities on Jupiter's moons would be even more hazardous than on our own moon, because the intense Jovian radiation belts engulf the satellites' orbits.

ASTEROID HURLING

Although planets and moons grab our attention, we can't ignore the smaller worlds around us. Our solar system is rife with rocky and metallic asteroids ranging in size from Ceres, with a diameter of 560 miles, to specks hardly bigger than dust motes. Many of the moons of the outer planets—including Mars's Deimos and Phobos—are undoubtedly former asteroids that fell into orbits around those planets.

Athletic contests on these worldlets where gravity is at a minimum could be exciting, even in space suits. An asteroid such as Gaspra (roughly the size of Manhattan Island) would have such low gravity that a person could throw sizable objects into orbit around the asteroid or even fling them to escape velocity.

A new sport could arise: asteroid hurling. There could be a variety of ways to score points: throwing stones of the same mass into the farthest orbit (without throwing them to escape velocity, beyond orbit, which would be considered a foul); throwing the most massive stone into orbit—a kind of asteroidal form of weight lifting; or throwing a stone into an orbit of predetermined radius around the asteroid.

On such small bodies, contestants with a powerful throw would have to be wary of lifting themselves off the asteroid as a result of their own exertion, which would leave them floating helplessly out in space.

INTERPLANETARY OLYMPICS

Athletic records set on our solar system's many worlds could not properly be compared with records set on Earth because of the totally different environmental conditions, just as records from any one world could not reasonably be compared with those from another. But records from one Olympiad to another on the same world could be compared against each other. Or an interplanetary Olympics could be held—*lasting* four years, instead of being held every four years—in which famous athletes travel from planet to planet, attempting to set new records for each local event.

Despite this fantastic notion, for some time to come sports beyond Earth will be the domain of amateurs—the workers and researchers who are on those other worlds to study them or build habitats or run the facilities erected there. The cost of space travel alone will not soon encourage professional athletics. Perhaps this is all to the good.

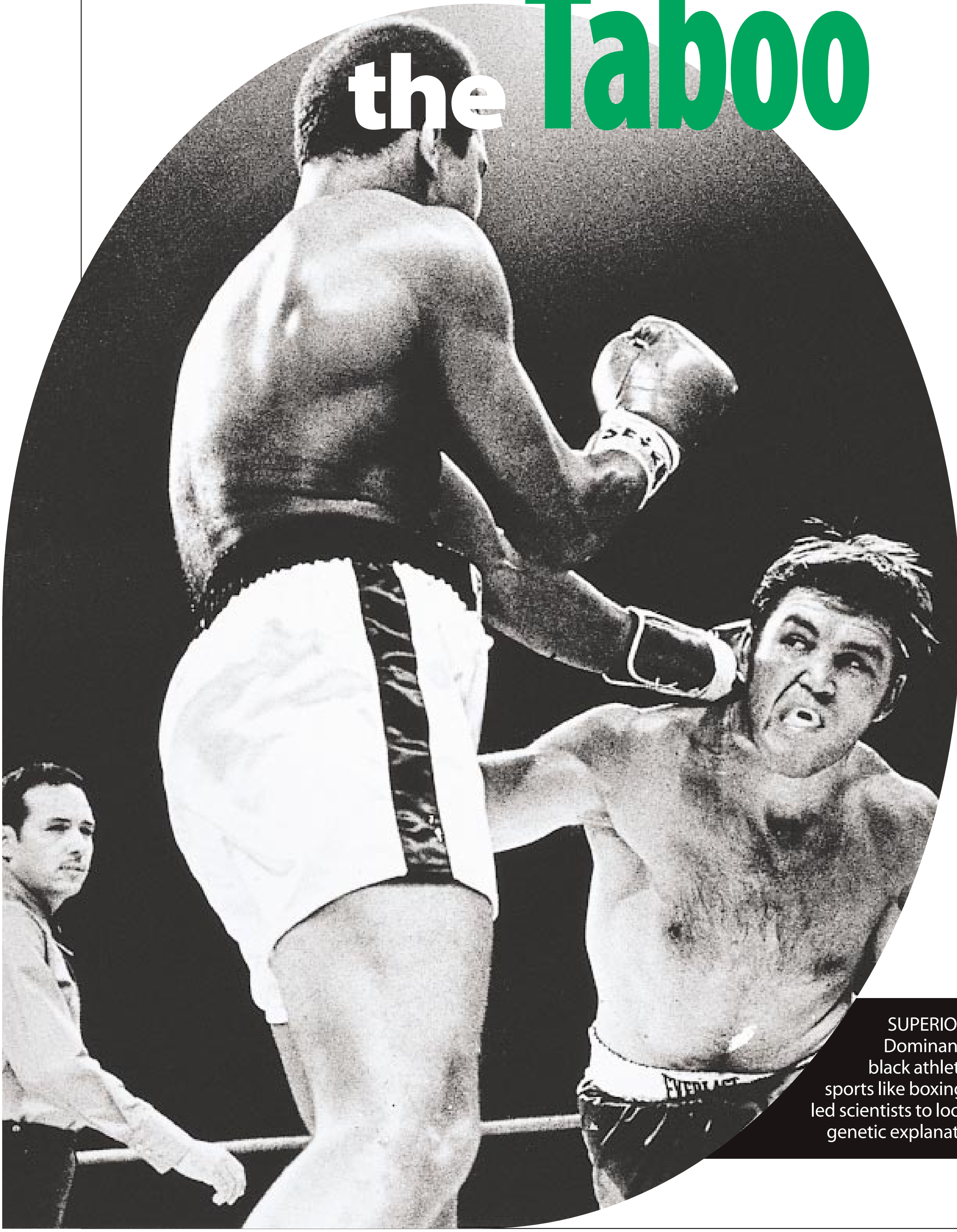
BEN BOVA has written more than 100 futuristic books about space development. He is president emeritus of the National Space Society and publisher of GalaxyOnline.com.

FURTHER INFORMATION

THE WIND FROM THE SUN. Arthur C. Clarke. Harcourt Brace Jovanovich, 1972.

WELCOME TO MOONBASE. Ben Bova. Ballantine Books, 1987.

Deconstructing the Taboo



SUPERIORITY: Dominance of black athletes in sports like boxing has led scientists to look for genetic explanations.

The intertwining of genetic, environmental and cultural influences makes it impossible to fathom why blacks dominate certain sports

by Gary Taubes

Last September a 20-year-old Kenyan runner named Noah Ngeny ran the fastest 1,000 meters in history, breaking a world record that had been set by British runner Sebastian Coe in 1981. Ngeny was a latecomer to the sport of competitive running. He had been a volleyball player until 1996, when he switched sports, he said, because "in Kenya, it's the runners who become national heroes." Ngeny had first tried to break Coe's record last July, in Nice in southern France, but fell short by less than half a second. The press reports of his September race suggest that he had carefully planned his second attempt. He chose a track in Rieti, Italy, in the mountains north of Rome that was considered to have the ideal combination of track surface, altitude and climate for record-breaking performances. Seven world records had been set there. Three days before the meet Ngeny persuaded the organizers to schedule a 1,000-meter race, which they had not originally planned on doing. The weather would be perfect—a beautiful, sunny afternoon. The end result of these preparations was the breaking of the oldest outstanding individual record in the books. It had also been the last record in competitive running—from 100 meters up to the marathon—not held by a runner from Africa or of African descent.

The domination of sports by black athletes has become one of the most remarkable phenomena of modern athletics. Blacks make up only 12 percent of the world's population, but take the top 100 times in almost any event in competitive running and you'll find that 70 percent are held by black athletes. In sprinting, the numbers are even more overpowering. In the 100-meter dash, the only runners ever to break the 10-second barrier have been black, and they have done so more than 200 times. And this predominance extends far beyond running. African-Americans constitute 13 percent of the U.S. population but 80 percent of the players in the National Basketball Association and 70 percent of those in the Women's National Basketball Association. Sixty-five percent of the players in the National Football League are black, and in those positions requiring speed and agility more than size, weight and strength, the appearance of a first-rate white player is inevitably hailed by fans and the sporting press as noteworthy. As *Sports Illustrated* put it in 1997, "The best athletes on the planet are black. Stop the conversation right there and few will argue the point."

It seems natural to proceed to the obvious next question, which is "Why?" But that's where the contention comes in, not to mention a century of acrimony and racism—from the riots that followed Jack Johnson's 1910 whupping of the Great White Hope, Jim Jeffries, for the heavyweight championship to the heated controversy surrounding a recent book, *Taboo: Why Black Athletes Dominate Sports and Why We're Afraid to Talk about It,* by Jon Entine. A former television journalist who co-wrote a notable 1989 TV documentary on the subject with Tom Brokaw, Entine concludes that although nature and nurture are inseparable, the "scientific evidence for black athletic superiority is overwhelming and in accord with what we see on the playing field.... Cultural explanations do not, cannot, account for the magnitude of this phenomenon."

MOST LIKELY TO SUCCEED

Whereas much of the science is hopelessly speculative, Entine's conclusions, echoing those of many researchers in the field, are based on a relatively simple line of thought: different athletic and sporting events require different body types and biomechanics. Long-distance runners benefit from being physically slight but having proportionally long, slender legs. Sprinters benefit from a preponderance of what are called fast-twitch muscle fibers. Height is an advantage in basketball and rowing. And even though culture, environment, diet, psychology, training, coaching and probably dozens of other factors all play necessary roles in the development of elite athletes, genes seem to endow some populations with a greater proportion of individuals who have the body type and biomechanics most likely to succeed—East Africans and particularly Kenyans in long-distance running; blacks of West African descent (including most African-Americans) in sprinting and in sports that require bursts of speed in running and jumping, such as basketball and football.

This may sound like common sense, but the scien-

ALLSPORT/HULTON GETTY

tific support for these conclusions is extraordinarily complicated, and the history so haunts the science that even to discuss it, as the subtitle of Entine's book suggests, is to tread treacherous ground. Over the years, the argument that blacks have an inherent capacity for athletic performance has frequently been accompanied by the suggestion that there is some inverse relation between brawn and brains. It is "the elephant in the living room," Entine writes. "A country nurtured on the myth that all people are created equal is understandably uncomfortable talking about innate differences, particularly when it comes to race. So when blacks are referred to as physically superior or natural athletes, hackles are raised. What's the *real* and *underlying* agenda?"

Historically, that agenda has often been racism as much as simple curiosity, scientific or otherwise. Nevertheless, the question "Why?" is hard to ignore, and it falls to science to offer a potential answer. The great tennis player Arthur Ashe, Jr., spent years of his life chronicling black athletic achievement in *A Hard Road to Glory.* When he was done, he was still unable to explain away the remarkable record of black athletes without evoking some inherent physical advantage. "I want to hear from the scientists," he said in Entine's 1989 documentary. "Until I see some numbers [to the contrary], I have to believe that we blacks have something that gives us an edge.... Damn it. My heart says no, but my head says yes."

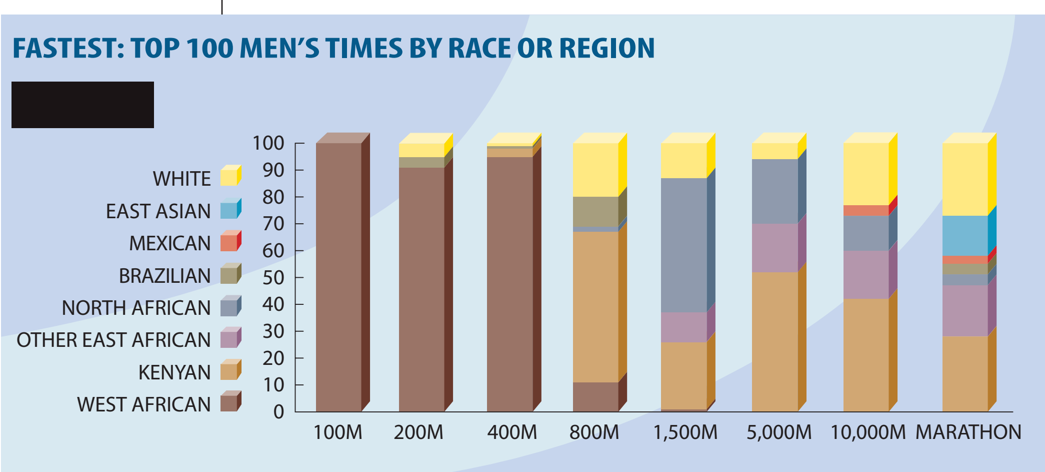
Those scientists, meanwhile, are often accused of racism for studying racial differences, even though they argue that this angle is inevitable when it comes to comprehending elite athletic performance. "If you want to understand what makes for excellence in different sporting activities, you have to study whoever is best at it," says Tim Noakes, a professor of exercise and sports science at the University of Cape Town in South Africa and the author of *Lore of Running.* "If you want to study the best runners, you can't study white Africans. You have to study black Africans. You can't ignore it."

The scientific issue and the accompanying disputation are further compounded by a host of other factors. What constitutes race, for instance, which is a fuzzy concept at best? Biologists will tell you that there is considerably more genetic variation among individuals of the same "race" than there is among the "races" themselves and that although skin color may seem to divide up the world into one set of "races," blood groups would divide it up entirely differently, and various genetic factors would split it in an infinite variety of other ways. And even the question of skin color can be deceptive or even meaningless: as University of California at Berkeley sociologist Harry Edwards writes, "The African American population arose from an admixture of European, American, Aboriginal and African stock. The issue emerges: how black does one have to be to make any sense of these things they are testing and talking about?"

Another complication, at least in the public presentations of the argument, is the twisted polemics about nature or nurture, or genes versus environment, rather than some hopelessly interconnected chicken-and-egg fusion of the two. "Saying it's all genes or all environment is a false dichotomy," says Michael H. Crawford, a University of Kansas biological anthropologist and geneticist. "For complex traits, whether you're talking stature or body mass or musculature or whatever, it's always the interaction of the genes with the environment, not one or the other."

WHAT ABOUT JEWISH COMEDY GENES?

The data required to decipher these interactions and to identify genetic elements that might endow certain populations with inherent advantages, then, can be considered either compelling, still ambiguous or beyond the realm of science to provide, depending on one's point of view. Entine and a fair share of researchers in this field believe that the empirical data are so powerful that it is sophistry to think that the genes shared by entire populations don't play a role, albeit one of many, in determining athletic excellence. Jonathan Marks, a biological anthropologist at Berkeley, argues precisely the opposite. "If anthropology has shown anything in this century, it's that a consistent observed group difference (from professional overrepresentation to skull shape) is not valid evidence of an innate basis for the difference. And the achievements of the few most extreme individuals are simply not a valid description of the population from which they are drawn," writes Marks in an uncomplimentary review of *Taboo* in the journal *Human Biology.* "Black dominance of basketball is thus no more an argument for sports genes



RACE IN THE RUNNING: Competitors of African ancestry (mostly black) hold the majority of leading times for the top running events, although only one of every eight people in the world is black.

LAURIE GRACE; ADAPTED FROM *TABOO*, BY JON ENTINE (PERSEUS BOOKS GROUP)

than it is for Jewish comedy genes, or Irish policeman genes."

The question, as Marks sees it, isn't whether blacks have "sports genes or not" but whether the question can be answered with any degree of scientific rigor: "In other words, what would it take to establish that black athletes are really better endowed than white athletes from the zygote? And the answer may be hard to swallow: Well-controlled experiments and data that begin by acknowledging the complexities of life histories, the poverty of rigorous data on the subject, the ease with which cultural stereotypes can be made to look like natural differences, and the difficulty in generalizing about the properties of populations from a comparison of the performances of their most outstanding members."

The process of scientific inquiry is about setting forth hypotheses to explain the available data and then rigorously testing those hypotheses to see if they hold up. The data here are the dominating athletic performances of African runners or those of African descent. The hypothesis is that these athletes have some innate biological advantages that arise genetically and bestow different advantages for different populations. But this hypothesis, Marks says, is virtually untestable.

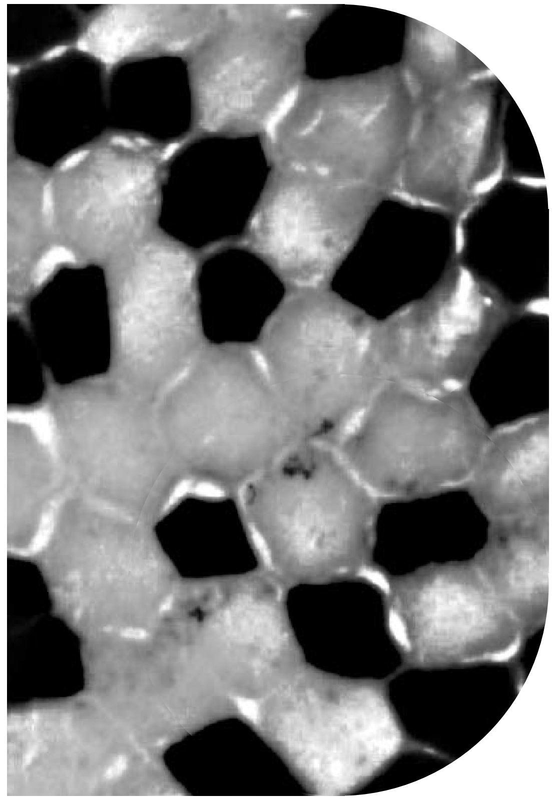
The number of variables that go into creating great athletes is enormous, and making sense of those variables is beyond the scope of science. Blacks are overrepresented in professional basketball, but so, for instance, are people from the nations of the former Yugoslavia.

Once a sport involves access to courts, playing fields, other top-notch players and a culture that encourages the endeavor, the data get intractably complicated. Are blacks underrepresented in competitive swimming, for instance, because they are, on average, less buoyant, as some data suggest, or because they have less access, on average, to swimming pools and swimming programs and so lack a culture of competitive success that would allow them to do well in the sport? And if it's the former, what about black underrepresentation in ice hockey? "Why does one kid become a boxer and another a doctor?" Marks asks. "That's a question for astrologers, not for scientists. Expectations, early tracking, ethnic or familial tradition, self-image, and of course opportunity are all forces that work with the genetic endowment. Unless those variables are controlled [for], one simply cannot make a reasonable scientific case for the latter's being the determining variable."

Researchers in this field tend to concentrate on running because the cultural and environmental variables are minimized. After all, anyone can compete as a runner, even without access to modern

RECORD BREAKER: Kenyan Noah Ngeny heads the line in a race in 1998. The following year, in Rieti, Italy, he broke the last world record in running held by a person not of African descent.

MIKE COOPER *Allsport*



HIGH-FIBER ATHLETES: South African researcher Tim Noakes found that elite black long-distance runners from his country, such as Willie Mtolo (*above*), had muscles with 40 to 50 percent fast-twitch fibers (*white areas in micrograph at right*), about the same as expected for runners of the mile, a middle-distance event.

coaching and training techniques or, for that matter, running shoes, as the great barefooted Ethiopian marathoner Abebe Bikila demonstrated in the 1960 Olympics. But even in running, the catch in accumulating rigorous scientific data is some catch: studying the biomechanical or physiological differences between populations—say, whites of European descent and blacks of East African descent—tells you nothing about the differences that contribute to great athletic performances, and studying the elite athletes tells you only about what elite athletes have that others don't. And if the elite athletes are almost all black, it tells you only about the nature of elite black athletes.

Tim Noakes learned this lesson firsthand. In South Africa whites dominated long-distance running for decades because only whites were allowed to compete. "Black athletes were first allowed to run in races with whites in 1976," he says. "By 1982 or 1983 it was very clear that black runners were beginning to dominate all events beyond five kilometers. In the half-marathon already 44 out of the top 50 runners were black." When Noakes began his studies of elite distance runners, he recruited the 10 top runners in South Africa, all of whom were black. "We couldn't find any white runners who could match them. So we took a group of white runners who were better at the mile to see if we could get some indication of black-white differences."

Noakes and his collaborators did find such differences, but the implication is anything but clear: the black runners were smaller on average—30-plus pounds lighter—than the white runners, and they had a different composition of muscle fibers. These fall into two categories: white, or fast-twitch, fibers, which are for speed and power; and red, or slow-twitch, fibers, which are for endurance. Sprinters are expected to have predominantly fast-twitch fibers, and marathoners predominantly slow-twitch. In the white runners, Noakes and company found precisely the ratio of fast- to slow-twitch fibers they'd expect in milers, in accord with previous studies of North American and European runners. In the black long-distance runners, they expected to find 80 percent slow-twitch fibers but found only 50 to 60 percent, about the same as in middle-distance runners. Is that why the black runners were so successful? Maybe. Maybe not. The data reveal nothing about cause and effect.

They also found that the black and white runners were equal in their ability to transport oxygen from lungs to the blood—a measurement known as VO_2max—but the black runners were able to run at a higher percentage of their maximum for considerably longer periods. That assuredly helps in long-distance running, but it could be the result of training rather than genes. All these results were interesting, but they said nothing definitive about black-white differences, only about the differences between marathoners (or half-marathoners) and milers.

MIKE SEGAR *Reuters/Archive Photos* (*left*); COURTESY OF TIM NOAKES (*right*)

"Is it a racial difference?" Noakes asks. "We don't know. And we can't really say, because you can never find anyone to match up to these black runners. They're tiny, and if you look at Caucasian runners, you don't find runners that small and fast. So that very difference prevents you from measuring it and saying it's due to a racial difference."

DIFFERING BODY TYPES

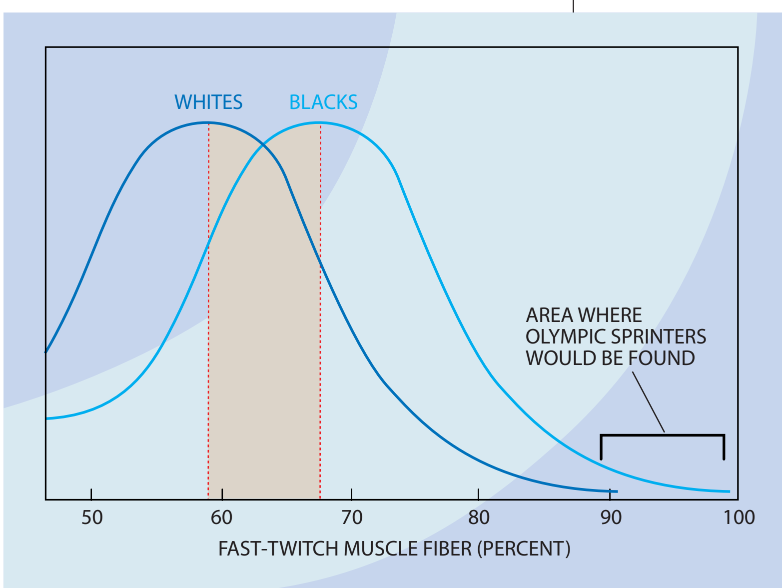
Researchers have consistently found that blacks and whites of different populations have, on average, slightly different musculature and skeletal proportions, but whether that translates to the differences in athletic performance is equally impossible to say. "There are proportional differences," says Michigan State University anthropologist Robert M. Malina. "Blacks have longer leg length, and the pelvis of blacks is a little bit more slender. If you look at the extremities, the differences are more apparent distally than proximally, which means blacks have a proportionally longer foot and lower leg than thigh. In the upper extremities, it means a proportionally longer hand and forearm than upper arm, compared with European and American whites. Blacks tend to have proportionally more musculature in their thighs. Black skeletons also tend to have a higher mineral content than whites; they are more dense."

The same variations have shown up in measurements of Olympic athletes, which suggests that such biomechanical features may explain the performance difference. Entine points out that since the 1928 Olympics there have been dozens of studies of Olympic athletes demonstrating that certain body types do better at certain events. "Only later did people looking at the data say [that] this falls in population patterns," he says. "This correlates with what we do know about general physiologic differences between population groups." J. E. Lindsay Carter, a professor of exercise and nutritional sciences at San Diego State University, did a series of anthropometric measurements on athletes in the 1972 and 1976 Olympics, and he concluded that the data are compelling, albeit not unequivocal. "From a biomechanical perspective, the answer is yes, race and ethnicity do matter," Carter tells Entine. "All of the large-scale studies show it; the data goes back more than 100 years." But then he adds that these are only tendencies: "There are far too many variables to make blanket statements. An average advantage, yes, but that says nothing about any individual competitor."

Claude Bouchard, director of the Pennington Biomedical Research Center in Baton Rouge, began studying the issue in 1980 at Laval University in Quebec when he realized that the ability to respond positively to exercise differed dramatically among individuals. Using sets of twins, he demonstrated that this "trainability" factor has a strong genetic component. But when he compared the trainability of sedentary blacks who had emigrated from West Africa with that of sedentary white Canadians, he found no appreciable differences. He did find that the blacks, on average, seemed to have slightly more fast-twitch muscle fibers than the whites did and "a bit more" of a key enzyme needed to generate energy from glucose. This might conceivably translate to an inherent advantage in sprinting, but those individuals with the higher levels were not the individuals who performed best in the trainability tests. "Do these biological characteristics make a big difference in performance at the elite level?" Bouchard asks. "We don't know."

On some level the challenge becomes one of statistics. Elite athletes are not like everyone else. And the very best are unique; they are the outliers on the distribution of humanity. "World-class sport is about extremes of performance," notes Stephen Seiler, an exercise physiologist at the Agder University College Institute of Health and Sport in Norway. "If there's just a small difference among populations, that might have an impact at the small percentage of the population that reaches these extreme values." Once again, however, this is a compelling hypothesis to explain the data, but it is only a hypothesis.

Geneticists and physical anthropologists have found that the DNA of black Africans has more genetic variation than that of other races. "African populations contain within them a tremendous amount of genetic variation," says Yale University geneticist Kenneth K. Kidd. "We've found that a single African population has as much, if not more, variation than all the rest of the world put together." This evidence suggests that such enormous genetic diversity results in a wider range of variation in inherent abilities among those of African descent in practically any situation that responds to a genetic component. "It's perfectly possible that for almost any trait you look at," Kidd points out, "you may find individuals at the extremes more common in Africa than elsewhere in the world—maybe not a lot more common, but somewhat. And whatever it takes to be an Olympic-class or professional athlete, you have got to start with some genetics. It's



FOR WHOM THE BELL CURVES: West African blacks, on average, had 67.5 percent fast-twitch muscle fiber (for sprinting), compared with 59 percent for French Canadian whites, suggesting that there should be more West Africans on the end of the curve at which it would be most likely to find Olympic sprinters.

LAURIE GRACE; SOURCE: "Skeletal Muscle Characteristics in Sedentary Black and Caucasian Males," by P. F. M. Ama et al., in *Journal of Applied Physiology*, 1986.

entirely possible that some groups have more individuals who have the physical type to excel, but it's never all individuals in the group. And then it's what those individuals choose to do with it." Still, Kidd adds, "it's not a matter of fact, by any means, but a possible extrapolation from what we know about the basic genetics."

AN INTRICATE TAPESTRY

One thing everyone in this field seems to agree on is that the nature-nurture/genes-or-environment split is mere casuistry. "The argument 'genes or environment' can never be phrased as a dichotomy," Kidd asserts, "because everybody is a product of both." Our physical and mental attributes are shaped by both genes and our environment, and athletic excellence arises from an extraordinarily intricate tapestry of both factors.

Take the Kenyans, for example. Bengt Saltin, director of the Copenhagen Muscle Research Center, has compared Kenyan runners with African-American sprinters and Caucasian runners. He found that the Kenyan long-distance runners seem to burn oxygen more efficiently and have more of a key enzyme that would allow them to burn fat as fuel more efficiently, an advantage that would come into play over longer distances. They also have what he calls a better running economy, which means that they need to expend less energy to run at any given speed than white distance runners do. This was "a striking finding," comments Saltin, who believes the explanation may be a basic biomechanical one. The Kenyan runners had longer and slimmer legs than the whites, who "had thicker legs and poor running economy," Saltin says. "And so the simple possibility could well be that just moving those legs back and forth is easier for the Kenyans. And that body shape, of course, is genetic."

But there may be more than that. You then also have to consider the environmental and cultural influences that might contribute to athletic excellence. John Manners, a former Peace Corps worker in Kenya and author of two books on Kenyan running, has spent much of his life studying just those potential factors—particularly among the Kalenjin tribe, which alone has garnered some 40 percent of the greatest international honors in men's distance running, including Olympic medals and record times. The Kalenjin live at altitudes above 2,000 feet, which, Manners writes, has "been shown to help create the high aerobic capacity that is vital to distance-running success." And they live in an ideal climate for running year-round, with "comfortably warm days, cool nights, low humidity." They are poor enough, with a per capita gross domestic product of about $1,500 a year, that life as a professional runner offers many incentives to train intensively for years—"even the meager winnings brought in by most professional or semiprofessional runners look pretty lavish," Manners says—but not so poor that they are malnourished or that the country lacks the resources to provide schools and a "fairly solid athletic infrastructure." And because the Kenyans began running competitively and with success in the 1960s, there is also a culture that encourages those who want to give it a try. Kenyan runners, as Ngeny observed, are national heroes.

All of that could be said, however, for peoples who

KALENJIN: This Kenyan tribe, which has garnered 40 percent of international honors in men's distance running, provides an ideal example of why it is impossible to determine whether dominance in a sport stems from genes or environment.

HEINZ KLUETMEIER *Sports Illustrated*

can't compete athletically with the Kalenjin, and so Manners went looking for traits unique to the population. "An obvious thought is that the Kalenjin might be endowed with some sort of collective genetic gift," he explains. "This is touchy stuff, of course, and there is nothing like replicable scientific data to support the idea." But there is some prima facie evidence supporting it: "The Kalenjin marry mainly among themselves; they have lived for centuries at altitudes of 2,000 meters or more; and, at least by tradition, they spend their days chasing up and down hills after livestock."

But, as Manners points out, there are still dozens of populations, if not more, around the world that are relatively poor, live at high altitudes and run all day long. What makes the Kalenjin so special? One possibility, he suggests, is that the tribe has a history of cattle rustling as a way of life, often trekking more than 100 miles to capture livestock. Manners speculates that young men better suited to this endeavor would prosper, and because cattle was a measure of wealth in Kalenjin society, the more a young man collected, the more wives he could buy and the more children he could father. "It is not hard to imagine that such a reproductive advantage might cause a significant shift in a group's genetic makeup over the course of a few centuries."

Finally, Manners credits the tribe's "austere warrior culture" that prizes more than anything an ability to withstand pain and deal stoically with intense pressure, which, after all, are two key aspects of long-distance running—including a series of "escalating physical ordeals" imposed on growing children that culminate with a circumcision rite that is "the central event in the life of every Kalenjin youth, anticipated for years with dread, and suffered with unblinking stoicism under the eyes of watchful elders, who are ready to brand a boy a coward for life if he so much as winces." As Manners concludes, any boy who can endure that kind of ordeal in his adolescence is unlikely to flinch under what he calls the "comparatively benign tensions" and the aches and fatigues of a tough race, even if that race is an Olympic final or in the pursuit of a world record. Perhaps with all these elements working in their favor, biomechanical and physiological factors come into play as well, but, as Manners acknowledges, one has to remain skeptical. The data might strongly imply, as the movie title puts it, that white men can't jump, but the history of science also makes it clear that strongly suggestive data can simply be misleading data.

GARY TAUBES is a California-based science writer.

FURTHER INFORMATION

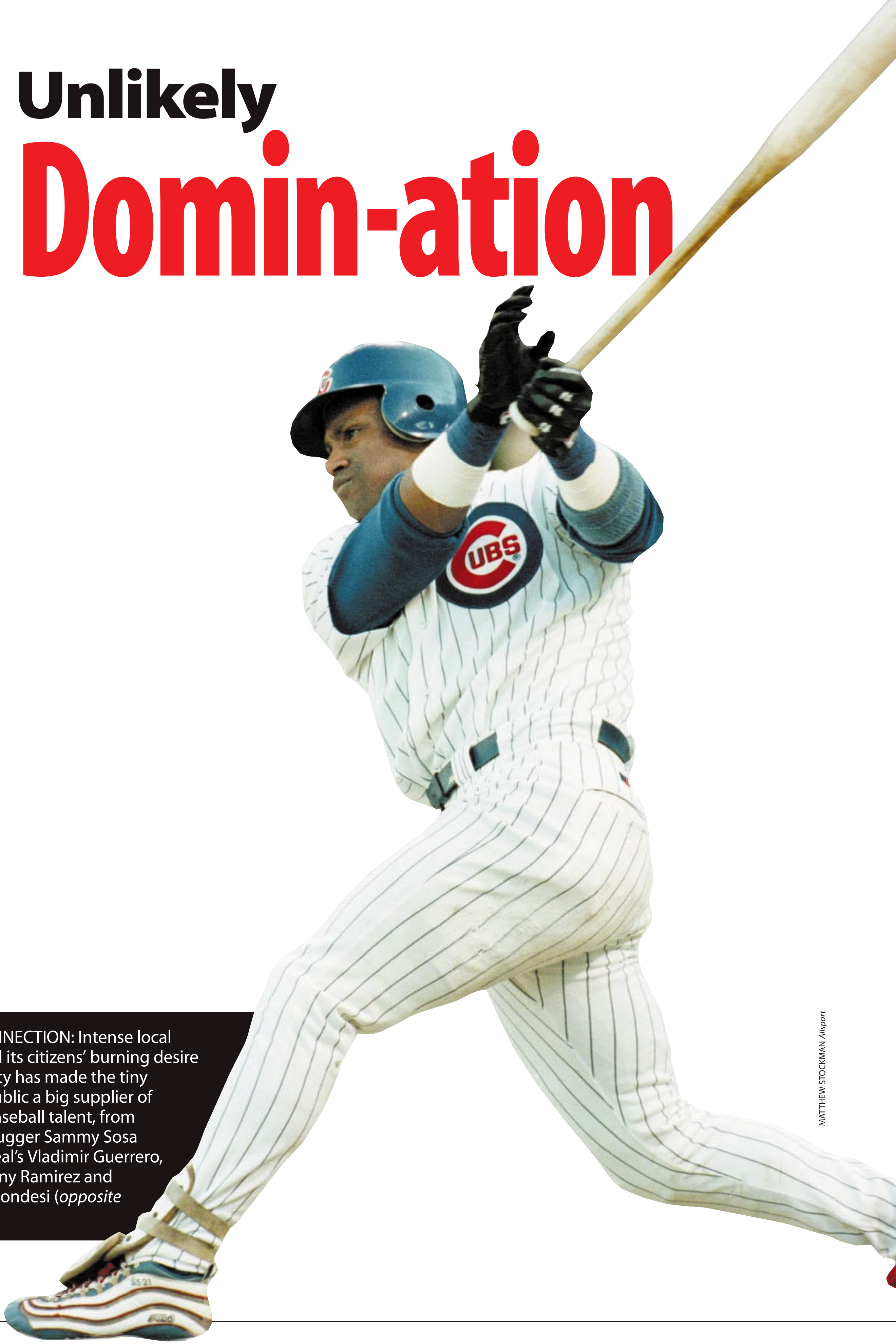
IS IT IN THE GENES? S. L. Price in *Sports Illustrated,* Vol. 87, pages 52–55; Dec. 8, 1997.

TABOO: WHY BLACK ATHLETES DOMINATE SPORTS AND WHY WE'RE AFRAID TO TALK ABOUT IT. Jon Entine. PublicAffairs (Perseus Books Group), 2000.

JUMPING TO CONCLUSIONS: A leap by dancer Mikhail Baryshnikov posed against a dunk by Michael Jordan muddies the cliché that white men can't jump.

F. MEDINA *Duomo/NBA (Jordan)*; BETTMANN/CORBIS *(Baryshnikov)*

Unlikely Domin-ation



CARIBBEAN CONNECTION: Intense local competition and its citizens' burning desire to escape poverty has made the tiny Dominican Republic a big supplier of Major League Baseball talent, from Chicago Cubs slugger Sammy Sosa (*right*) to Montreal's Vladimir Guerrero, Cleveland's Manny Ramirez and Toronto's Raul Mondesi (*opposite page, from left*).

MATTHEW STOCKMAN *Allsport*

Dominican baseball players. Chinese Ping-Pongers. Why do certain countries, even poor, tiny ones, dominate certain sports?

by Reinout van Wagtendonk

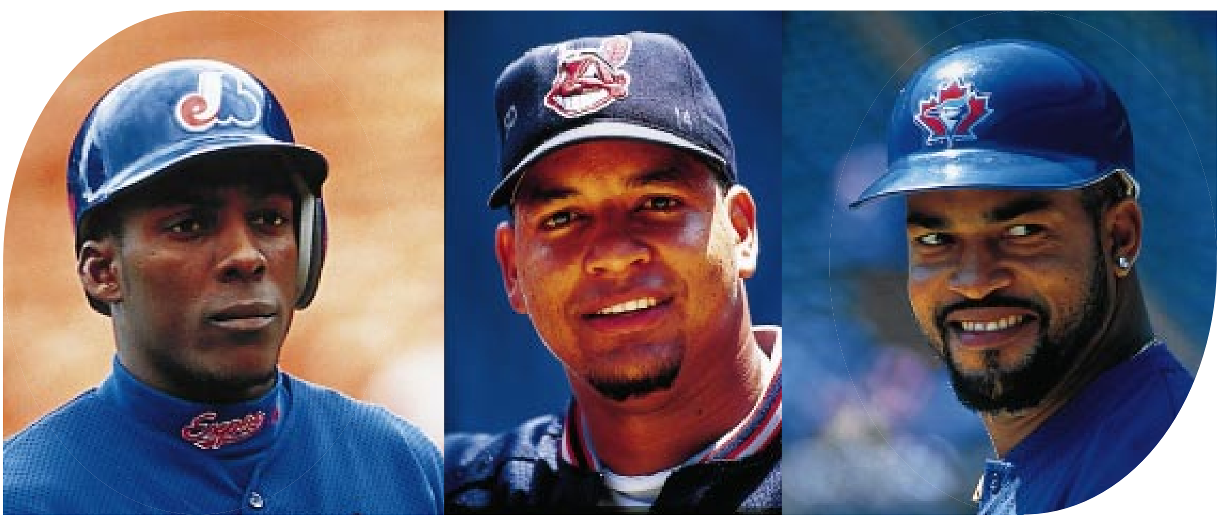
Think snow. Think wintry Alps. It seems obvious that Austria would be home to "The Herminator," the world's dominating downhill skier, Hermann Maier. Steep mountains and many months of fresh powder—of course Austria produces gold-medal skiers. Hasn't it always?

"Actually, the British brought alpine skiing to the Alps," says Allen Guttmann, a professor of history at Amherst College and author of *Games and Empires,* which examines the spread of modern sports. "The native people in Switzerland and Austria moved about on skis, but they didn't make an organized sport out of downhill skiing. The first alpine club was founded [in 1903] in London."

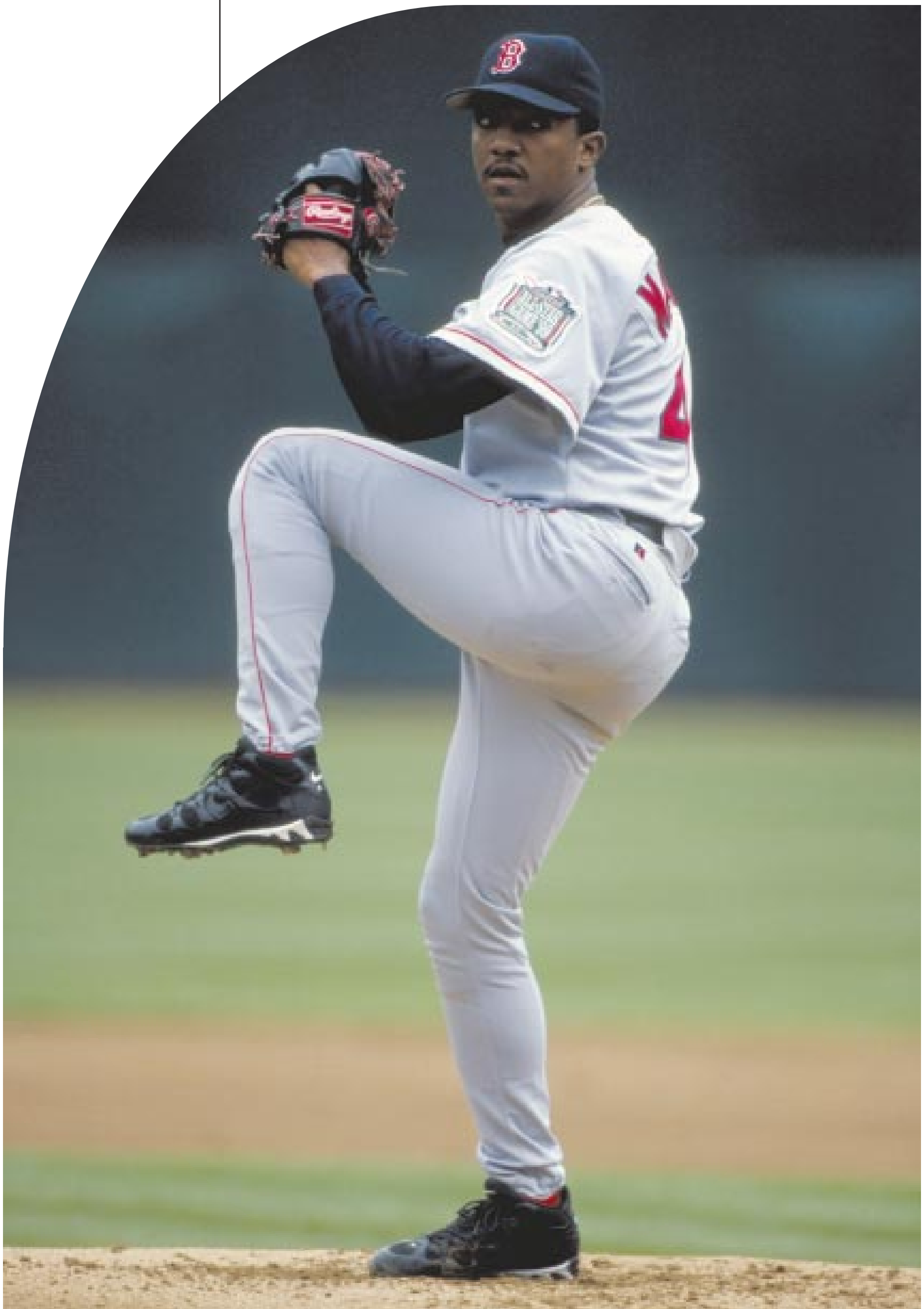
The role of mostly snowless, mostly mountainless England in organizing skiing as a sport illustrates the British Empire's enormous influence on the propagation of modern sports to all corners of the world. It also illustrates that the geography of sports is not as simple to map out as it may appear. Dominance in a sport is ultimately not about physical geography or a nation's population or wealth, it's about the geography of power.

On closer examination, popular notions about why certain countries are hotbeds for star athletes often prove to be fallacies, particularly when the country is tiny or poor. Baseball fans, for example, know the Dominican Republic as the largest supplier of foreign players to Major League Baseball in the U.S. Home-run giant Sammy Sosa, pitching ace Pedro Martinez, third-base sensation Adrian Beltre and dozens of their countrymen earn millions of dollars with their skills. But has anybody ever heard of a Haitian prospect with a major-league arm? The Dominican Republic shares the Caribbean island of Hispaniola with Haiti; both countries enjoy the same languid climate that is perfect for year-round baseball. What's different?

Kenya is another anomaly. The East African nation is known the world over as the commanding presence in distance running. Kenyan middle- and long-distance runners first came to broad public attention at the 1968 "high-altitude" Olympic Games in Mexico City, where Kipchoge Keino, Naftali Temu and Amos Biwott won gold medals. Sports commentators were swift to attribute their success to Kenya's highlands. But since then, Kenyan runners have expanded their dominance, winning races at sea level and in all climate zones. Besides, if high-altitude preparation is all



CHRIS TROTMAN *Duomo* (Guerrero); GREG FIUME *Duomo* (Ramirez); GREG FIUME *Allsport* (Mondesi)



MONEY BALL: Dominican Pedro Martinez, the 1999 American League Cy Young Award winner, has pitched his way to prosperity.

JED JACOBSOHN *Allsport*

it takes, then where are the world-class runners from similarly situated countries, such as neighboring Tanzania or Uganda or countries in the Andes or Himalayan regions?

SOCIAL ROOTS

Away from the daily sports pages, historians, sociologists and anthropologists have written extensively about why certain countries produce a disproportionate number of world-class athletes in certain sports, often despite small populations and widespread poverty.

One big reason is simply that the fervent, sustained popularity of a single sport will create world-class athletes, says University of Amsterdam professor Ruud Stokvis, a social scientist who specializes in sports history. It's baseball in the Dominican Republic, running in Kenya's Rift Valley, table tennis in China, field hockey in India and Pakistan, soccer in many other countries. So what has created that sometimes very localized fervor?

In earlier times scholars maintained that there was a link between the "ethnic character" of a country or its people and the characteristics of their favorite sports. But in today's age of multiculturalism and globalization, most modern academics reject this notion. The evidence is plain, too; baseball, for example, is widely popular in the U.S. and Japan, two countries with extremely different cultures.

"You have to go back and examine the social characteristics of a sport for your first answers as to why a particular country produces champions in a particular sport," says Maarten van Bottenburg, another Dutch sports sociologist and author of *Hidden Competitions*. "Where did a sport originate, who introduced that sport in another country and with what aim, and which part of the population adopted the sport?"

Many social roots trace back to England. Before the 19th century, sport-like games were played according to a wide variety of local rules and traditions. Britain's "public schools"—the private boarding schools where the elite sent their sons—played an essential role in molding these games into standardized sports. "Schools like Rugby and Eton were very violent places in the 18th century," Guttmann says. "It occurred to 19th-century headmasters that sports might be a way to tame the young gentlemen, to civilize them."

"At the same time," adds David Levinson, an anthropologist and co-editor of the *Encyclopedia of World Sport*, "the riches coming from the British colonial empire supported a leisure class that could afford to play games, that could travel to Switzerland for three months to go skiing just because it looked like a fun thing to do. It wasn't necessarily about competition. You'll notice that as the empire faded, so did British sports dominance."

Many games began with this elite pedigree: soccer, rugby, cricket, field hockey. But soccer quickly became the sport of choice for the urban masses in England's industrial centers, both to play and to watch. The surest sign of its popularity was the early introduction of professionalism—pay for play—which was an abomination to the upper classes.

Because it caught on with the commoners, soccer was often brought to other cultures by British sailors, enlisted soldiers or tradesmen. Across the globe, the sport caught on as the people's game, spreading into broad social classes without much more purpose than enjoyment.

But as a colonial power, Britain ferried other sports abroad much more discriminately. Administrators, educators and other colonial masters exported their less democratized games wherever the Union Jack flew—the Asian, African and Caribbean territories. Often the games were sustained for the ruling classes' own amusement in the "upstairs, downstairs" atmosphere that they created wherever they settled. Sports were also made part of the curriculum of the British-style schools where the sons of the local upper classes enrolled to prepare for their part in England's rule. And as was done in the 19th century, public school headmasters who discovered these organized sports introduced them as a way to tame their own unruly pupils, as an instrument of control over the native population.

This begins to explain the rise of Kenyan running. "The introduction of sportized running and other Western sports into Kenya was explicitly meant as a form of social control, as a safety valve against excessive anticolonial feelings," says John Bale, a professor of education and geography at England's Keele University and co-author of *Kenyan Running*. "Studying the archives made that very clear. There are all sorts of quotations from British colonial officers about how sports will stop these guys from stealing cattle, how it will keep them quiet and subdue them."

Native Kenyans were also recruited for police and army services. Hard physical training to assure their fitness was a priority, especially after R.G.B. Spicer arrived in 1925 as commissioner of police. Spicer was an all-around sportsman. His emphasis on athletics in his force produced a team of policemen-athletes that dominated the so-called African Olympics in those years. Schools, premier among them the Jeanes School, founded by American philanthropists, contributed to the development of Kenyan athletics. Foreign missionaries played a crucial role, too, introducing Western sports as a part of their efforts to remake native culture more in their own image.

What that proves to Bale is that the dominance of Kenyan long-distance running today cannot be explained through inherently local factors. It's not only high altitude, or just a hypothesized genetic advantage in members of the Nandi tribe (which produces so many world-class Kenyan distance runners), and not the jolly folkloristic belief that Kenyan children perhaps run long distances to get to school (most don't, according to Bale's research). The first Kenyan who impressed track-and-field aficionados was Nyandika Maiyoro, who in 1954 in a three-mile race in London kept pace with British world-record breakers Fred Green and Chris Chataway. The 1968 Olympic gold medalists and dozens of top runners have since followed in Maiyoro's footsteps.

The Kenyans did not burst on the scene as "natural athletes" (read: unsophisticated blacks who just happen to be born fast). "There had been a strong program of development going on at least since the 1930s," Bale says. "One can only explain the emergence of Kenyan runners by taking the influence of missionaries and other foreign teachers into account and their enrollment in the police force, the army and all those kinds of Western agencies that stimulated athletics."

Kenyan runners have now clearly become an export product. International sports agents, the organizers of marathons and other track meets, American universities aiming to boost their prestige with National Collegiate Athletic Association (NCAA) running titles, and the world's large athletic-shoe companies all mine their talents. Likewise, the Dominican Republic has become a "baseball plantation" for American major-league teams, in the words of Northeastern University anthropologist-sociologist Alan Klein in his book *Sugarball: The American Game, the Dominican*

WIN WIN: Kenyans Elijah Lagat and Catherine Ndereba won the 2000 Boston Marathon. Colonialists, missionaries and police recruiters all influenced Kenya's rise in distance running.

AL BELLO *Allsport (top and bottom)*

BLOODBATH: Political hatred can motivate rivalry. This Hungarian water polo player emerged battered from a 1956 Olympic match with the Soviets, whose country had invaded Hungary that same year.

Dream. There's lots of raw talent there that can be developed cheaply.

A bit of history is necessary to understand why the Dominican Republic, a poor country of only eight million people, has become such a prominent supplier of superior baseball talent. As British sports started to spread globally in the late 1800s, the U.S. became a world power with its own identity, economic might and political sphere of influence. It also began to separate culturally from Britain. It was baseball, not cricket, that became America's dominant bat-and-ball sport. (Guttmann says that "the absolutely wacky notion" that Abner Doubleday invented baseball in 1839 in pastoral Cooperstown, N.Y., is a myth designed to deny the obvious British roots of the great American pastime.) Neither soccer nor rugby but the American football variation took hold in the U.S. Baseball became the sport of the masses, professionalism and all. As Britain had done, America bundled its game into the economic and cultural hegemony it built in Latin America, Cuba and most of the rest of the Caribbean—and, to a lesser extent, in Japan, the Philippines and other parts of the Far East.

FOCUSED: The Chinese concentrated on table tennis to beat rivals from imperialist Japan. Linghui Kong ranks first in the world; three of his countrymen round out the top five.

"Note on a map which countries play predominantly soccer and which play baseball, and you'll know if it was Britain or the U.S. that held sway there around the beginning of the 20th century," Stokvis says.

Baseball came to the Dominican Republic when a Cuban slave revolt in 1868 forced many upper-class Cubans with American connections to move there. Along with their sugar plantations and refineries, they brought baseball. In a classic pattern, periodic occupations of the republic by the U.S. Marines strengthened both emulation and resentment of the dominant power.

The rich Cuban sugar barons liked to bet on the teams they fielded. Rather than stock their teams with dilettante players from their own social class, they recruited the best players from the working class—their own farm and factory hands—to ensure victory on the diamond. Longtime Dominican dictator Rafael Trujillo was so determined to have his Ciudad Trujillo Dragons win championships in the 1930s that he lured the legendary Satchel Paige, Cool Papa Bell and Josh Gibson from the American Negro League. The rivalries among the economic and political elite fostered the highest-level pennant races outside the American majors.

This laid the foundation for the later individual successes of Dominican players in Major League Baseball, Klein argues. "It's not that there is inherently more talent there," he says. "Baseball is practically the only way out of dead-end poverty. Sports can provide upward mobility. But if it was simply poverty as an incentive that drives kids to try to excel, then we would also expect to see as many ballplayers come from Mexico and other places. It is a combination of the poverty plus the incredible caliber of competition that developed early on, driven by the refinery owners and others in the ruling class striving to outdo each other."

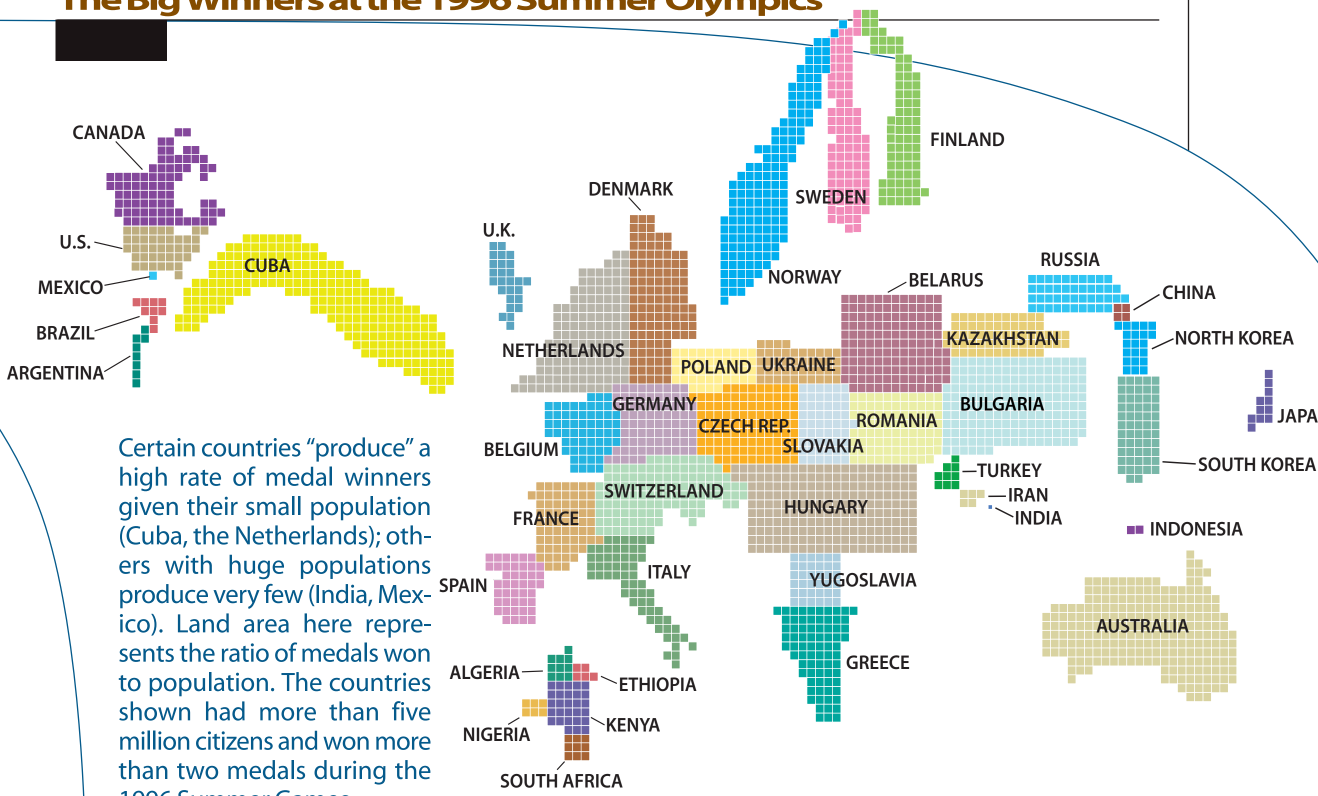
DRIVEN BY RESENTMENT

Aside from England and the U.S.—where "muscular Christianity" and the Young Men's Christian Association gave the world basketball and volleyball—Japan has been the nation most responsible for the spread of organized sports. Modern table tennis came from England, but a Chinese shop owner imported the first equipment to his country from Japan in 1904. Since the mid-1900s Chinese players have won more than 50 table tennis world championships. Their ascension has sprung in part from two distinct factors: paddle grip and resentment.

The British had one style of grip, which was emulated at

BETTMANN/CORBIS (*top*); JOHN GICHIGI *Allsport* (*bottom*)

The Big Winners at the 1996 Summer Olympics



Certain countries "produce" a high rate of medal winners given their small population (Cuba, the Netherlands); others with huge populations produce very few (India, Mexico). Land area here represents the ratio of medals won to population. The countries shown had more than five million citizens and won more than two medals during the 1996 Summer Games.

LAURIE GRACE

English YMCAs in China's large trading cities. But the Japanese had developed a different paddle grip. This cultural crosscurrent led to a variety of grips in China, which may have contributed to early successes in a sport in which the spin put on the ball through various ways of striking it is so important, according to Susan Brownell, professor of anthropology at the University of Missouri and author of *Training the Body for China*.

Meanwhile, Brownell says, expert play was also driven by Japan's regional hegemony in the first decades of the 1900s. "Knowing that the Japanese were good at this made the Chinese concentrate on it just that much more," she says. In his travels at the time of the communist takeover, China expert Edgar Snow observed the role of the Red Army in spreading table tennis to even the most remote areas of the country. Since table tennis became an Olympic sport in 1988, Chinese men and women have won nine gold medals out of a possible 12.

Resentment and rivalry from a less dominant country toward a stronger one have always been powerful motivators in the development of sports, Guttmann argues. Between 1928 and 1984 India and, to a lesser extent, Pakistan dominated the Olympic field hockey tournaments, winning 11 out of a possible 13 gold medals. Neither country is visible in other world sports. The two countries initially grew strong in field hockey to beat the imperial Brits. But after their hard-fought independence, bitter hostility grew between the neighbors. The war of words and deeds continued on the field hockey pitch, where Indian and Pakistani players literally bloodied one another in heated matches. Though twisted, this intense competition could further explain the desire of the people in these two cultures to excel in the sport.

Similarly, Hungarians and Czechs have waged legendary, bloody battles in water polo and ice hockey, respectively, against Russian teams ever since the Soviet invasion of Hungary in 1956 and of Czechoslovakia in 1968. "To beat them at their own game," Guttmann says. "Don't underestimate that as a driving force. It's about the only way that many of the less powerful countries will ever be in the headlines. It's the only time that their flag will ever be hoisted before the eyes of the world. They can't hope to compete in the economic realm or in science. They're not going to send the first manned spaceship to Mars. But they can produce Olympic athletes who will stand there on the victory podium while the whole world is watching."

REINOUT VAN WAGTENDONK is U.S. correspondent for Radio Netherlands World Service and other international media.

FURTHER INFORMATION

THE GLOBAL SPORTS ARENA: ATHLETIC TALENT MIGRATION IN AN INTERDEPENDENT WORLD. Edited by John Bale and Joseph A. Maguire. Frank Cass & Co., 1994.

GAMES AND EMPIRES: MODERN SPORTS AND CULTURAL IMPERIALISM. Allen Guttmann. Columbia University Press, 1996.

A SPHERE AND PRESENT DANGER

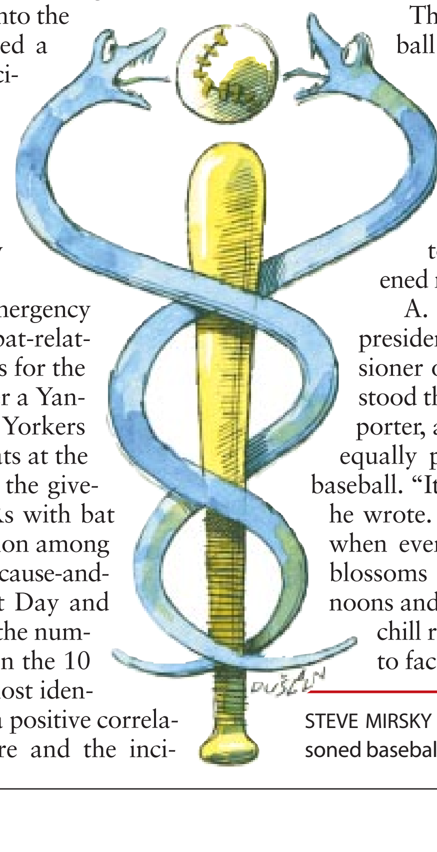
by Steve Mirsky

Stand in against a baseball being thrown at anything approaching the velocities achieved by major league pitchers, and you experience an epiphany: the ball makes noise. The air, combed by the seams and whipping over the white, produces the buzz of some massive, malevolent insect. Yes, the ball actually sounds like Randy Johnson looks.

The hum is a perceptible reminder that baseball, that most pastoral of pastimes, often puts its players in harm's way. Less appreciated is baseball's potential danger to the public. Sure, there are those ringing line drives into the stands that occasionally conk the innocent. And entire bats sometimes fly from the hitter's hands to wreak havoc on the residents of the box seats behind first or third. But there are more insidious risks.

One baseball threat loomed above all others, at least in the eyes of emergency clinicians in New York City: Yankee Bat Day. The impression among such physicians was that the annual unleashing of 25,000 kids with spanking new clubs onto the streets of the Bronx precipitated a flurry of bat blunt-trauma incidents. This assumption was tested in a study published in 1994 in the *Annals of Emergency Medicine* entitled "Impact of Yankee Stadium Bat Day on Blunt Trauma in Northern New York City."

The report's authors, three emergency medicine physicians, followed bat-related visits to 10 emergency rooms for the 10 days before and 10 days after a Yankee Bat Day. Enterprising New Yorkers must have had a stockpile of bats at the ready—in the 10 days prior to the giveaway, 38 people visited the ERs with bat injuries. Contrary to the suspicion among "emergency clinicians about the cause-and-effect relationship between Bat Day and bat trauma," the authors note, the number of patients who presented in the 10 days after the event was an almost identical 36. There was, however, "a positive correlation between daily temperature and the incidence of bat injury." Apparently, if you can't stand the heat, whack someone.



The belief in post–Bat Day madness extends beyond the bucolic Bronx, at least as far as South Carolina. An attorney offered to sponsor Bat Day for the Class A South Atlantic League's Charleston RiverDogs, as long as the bats included his logo, in reverse, on the business end. "The offer was in jest," assures RiverDogs vice president and general manager Mark Schuster, "but the idea was that the bat would leave a mark that the victim could read and instantly know who to call to sue."

Of course, the danger of Bat Days pales in comparison to the risk of complications from an actual surgical procedure briefly offered by the RiverDogs in 1997: a possibly lucky male fan would have walked away, slowly, as the winner on Vasectomy Night. Schuster says that the public outcry convinced the team to nip that idea in the bud, despite the vas deferens it would have made in one man's life.

The biggest health threat to the baseball fan, though, is the one familiar to any who have loved not wisely but too well. The famous Framingham, Mass., studies of cardiovascular disease have never bothered to correlate morbidity with devotion to the nearby Boston Red Sox, who have long sickened more hearts than any high-fat diet.

A. Bartlett Giamatti, the one-time president of Yale University and commissioner of Major League Baseball, understood the special suffering of the Sox supporter, as well as the more pedestrian but equally poignant pain felt by all fans of baseball. "It is designed to break your heart," he wrote. "The game begins in the spring, when everything else begins again, and it blossoms in the summer, filling the afternoons and evenings, and then as soon as the chill rains come, it stops, and leaves you to face the fall alone."

STEVE MIRSKY pitches in as *Scientific American*'s seasoned baseball-batty editor.

DUSAN PETRICIC