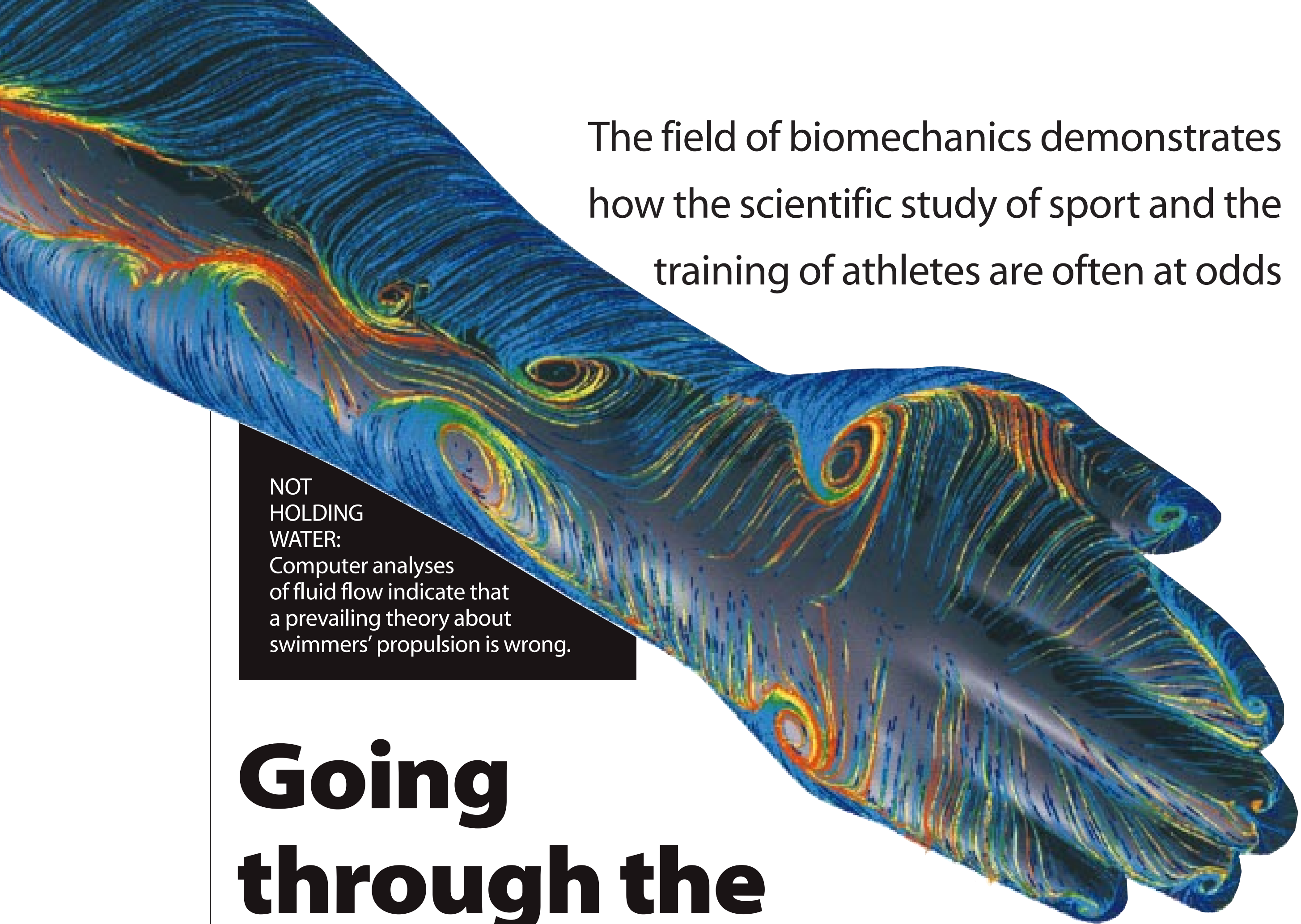


The field of biomechanics demonstrates how the scientific study of sport and the training of athletes are often at odds

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.

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.

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

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."

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

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

COURTESY OF SPEEDO

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.

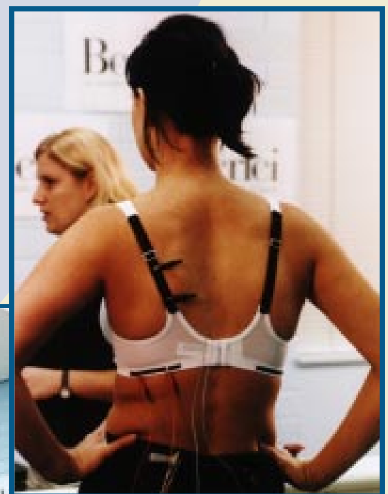
## KEEPING ABREAST OF NEW TECHNOLOGY

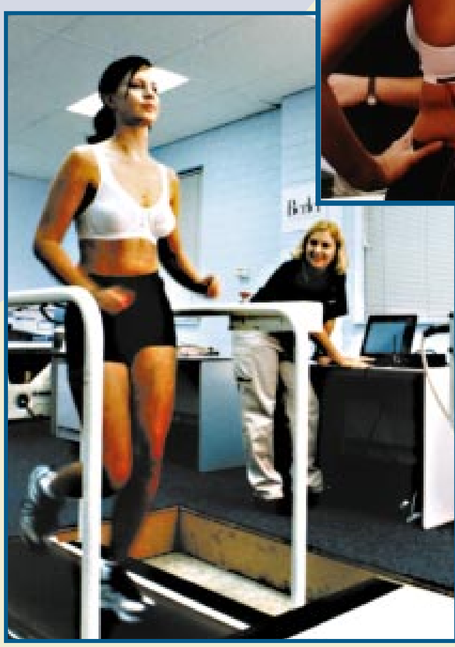
[redacted]

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*