Moving

No pain, no gain

Sports science and environmental adaptation from a biological standpoint

We really think about air, and probably ponder air pressure even less. But the earliest life forms lived in a completely different environment than we live in today. Somehow they survived. In the field of sports science, we have begun to try and awaken the capacity for evolution and adaptation that is asleep inside our bodies.

Training muscles, training nerves
The flying weight lifters

Among world-class Olympic athletes, who can jump the highest? Volleyball players? While vertical jumps of more than 70 cm are not unusual, athletes from one sport can go far beyond this, jumping as high as 1 meter.
These are the weight lifters.
Since this is not a jumping sport, and weight lifters don't run during competition, what is the point of jump training? Why do they need this? Sports science offers some interesting answers to these questions.

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The construction of a 7-story building for the Department of Sports Sciences, Japanese Institute of Sports Sciences, appears to be nearing completion as we can see lights in some of the windows. With a total floor area of approximately 27,500 square meters, the building looks as big as a military base. We are going beyond it to another building containing an equipment assembly area.
Kazuo Funato, a researcher in the Department of Sports Sciences, Japanese Institute of Sports Sciences, is quite excited about the future. He explained: "The main building looks like a huge battleship. It's scheduled to open next spring and start being used in the fall, when it will clearly become the world's top center for sports science."
The most impressive aspect of the center are its vast facilities, which include a 50-meter pool, a synchronized swimming pool, a 100-meter track, a shooting range, judo rooms, fencing rooms, and even an artificial canoeing river that lets you control the speed of the current. All of this is inside one building, and the facilities are only part of the excitement.
"America and Australia both have national training centers, but they were built mainly to give athletes a place to train. If necessary, video and still cameras can be set up to support athletes at these facilities. But our center was specially designed with recording devices so that athletic training, sports science and medical research can be done in parallel."
For example, the 50-meter pool has a light that travels along the bottom of the pool at the speed of the world or Japan record. This lets swimmers try and pace themselves with record-breaking speeds. There is also an observation window, much like in an aquarium, for video and photographs. The pool walls are even fitted with 'force plates' that measure how strongly you kick the wall, and in what direction.
"The force plate contains an extremely precise scale that measures force in the x-, y- and z- directions. Such plates are used in about 100 locations in the center, including the circle for hammer throwing and the area where rifle shooters stand. There are 16 force plates installed in the 100-meter track so we can precisely measure the force of your right and left foot at the starting block, during early acceleration, at a midpoint and at the finish line."
In other centers, a detailed video analysis of a training session is usually available to athletes after several days. Such an analysis can be viewed here almost instantly.
"If someone tries to analyze your golf swing or give you some pointers after you've shot a round, you may not be able to fully digest everything they're saying. At this center, we try to produce objective data on an athlete's performance before their body forgets the actions they just performed."
Preliminary data from the shooting range (not available for publication) shows the shooter's balance, the parts of each foot that bear weight, how the arms hold the gun, heart rate, breathing rate, muscle shrink ratio and even the amount of teeth clenching. Ready to shoot? Your heart beats approximately once per second, and you need to pull the trigger in between each heartbeat.
To study complex systems of motion, you must become an expert on every action performed by an athlete. A leading sports scientist, Mr. Funato is also a member of the medical committee for weight lifters. So why do weight lifters have such tremendous jumping power? (See figures 1 and 2.)
"We measured the amount of force a weight lifter pushes into the floor by positioning a force plate under each foot. As you pull up a barbell the force gradually increases, and then drops suddenly. This is the point when lifters suddenly bend their knees and quickly hoist the weight to a new position. The change in

Kazuo Funato
Researcher, Department of Sports Sciences, Japanese Institute of Sports Sciences.

force here is similar to that of a vertical jump. In a latter part of the lift, their feet again kick into the ground with great force. Would you believe that immediately following this, the force goes to zero? This means the athlete's body and the barbell are momentarily floating in space."

Weight lifters perform similar movements to those in vertical jumping, but also push up more than 100 kg of extra weight. No wonder their jumping power is so tremendous.

Optional training, even in outer space

Sleeping with less oxygen

If you want a flat stomach and do 30 or 40 sit-ups a day, you may be unsuccessful. The problem, surprisingly, is the large number of sit-ups.

"A muscle will not become thicker unless you exercise it at 70 percent or more of its maximum load. Since a 70 percent load can be lifted a maximum of 15 times, if you can do 30 or 40 repetitions your load is too light for muscle training."

On the other hand, if your load is too heavy you cannot do enough repetitions to be effective.

"We've also discovered that training with a 95 to 100 percent load is sometimes necessary. Even if you can only do one repetition, sometimes it's enough. This trains the nervous system. Muscles consist of many strands of fiber, and when you need a small amount of power, you use your small fibers (slow fibers). When you need more power, you engage the large muscle fibers (fast fibers). To utilize large muscle fibers, however, a very strong electrical stimulation from the brain is required."

This is analogous to a pinch hitter in baseball, who doesn't even enter the ballpark till the high point of the game. You need at least a 70 percent load to train your largest (fastest) fibers. In addition, several times a week you should lift your load limit, a 100 percent load, to train your body's electrical stimulation system. While using a 100 percent load might seem like an outdated method akin to making loud voice when training, but it makes sense from the perspective of training the nervous system.

"Some people think if you take a day or two off your condition will deteriorate. Or that your performance in an actual event can never match that of your training sessions. We consider such issues and problems to be related to your nerves. We understand how to thicken muscles, but far less is known about the nervous system."

We can evaluate the effectiveness of a given training method by its results. Coming up with a good theoretical explanation, however, is not always so easy. Low-oxygen training, for example, strengthens your breathing system so it can more effectively deliver a limited supply of oxygen to fuel your muscles. With this method, the amount of hemoglobin carrying oxygen in your bloodstream increases and your capillaries expand. We often speak of such adaptations. Still, how low should the oxygen level be for such training to be effective?

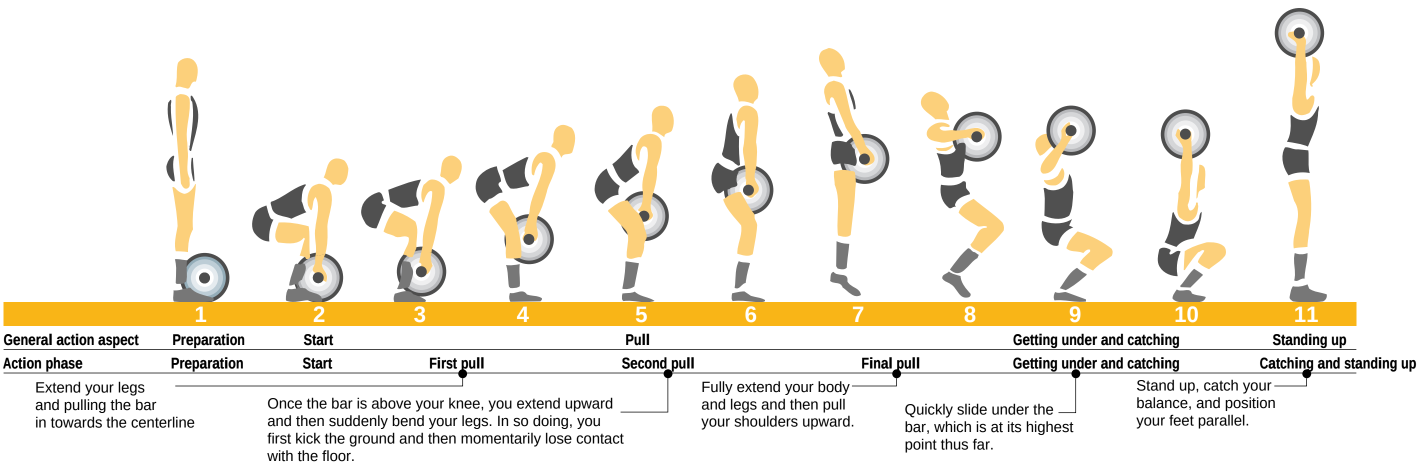
"Generally speaking, high-altitude training is best when done between 1,500 and 2,000 meters. But Naoko Takahashi, marathon winner in the 2000 Olympics, trained at 3,500 meters. Most runners would never train at such a high altitude because of the danger of brain anemia. So what was her training method? She concentrated on increasing her non-oxygen related energy source, the large (fast) muscle fibers. This may be why she won a gold medal. One of the roles of sports science is to develop theories that explain the unique training methods used by sports pioneers like Takahashi."

Similarly, sports scientists in the future will seek to provide an environment for athletes who want to be such pioneers. At the Department of Sports Sciences, Japanese Institute of Sports Sciences, we have a low-oxygen sleeping room. Not only can you train under low-oxygen conditions, you can live your life there.

"Normal air is comprised of 20.9 percent oxygen. We can reduce this to 15 percent to simulate the atmosphere at 2,500 to 3,000 meters."

I can imagine a TV reporter coming here and saying, "I'm not going to sleep here, I can't breath."

■ Figure 1 Weight Lifting Movement: the "snatch"



"We have a medical research room that always has a doctor on duty, so you don't have to worry. Many winter sports athletes, including Kenji Ogiwara, already do low-oxygen training. We leave it up to the athletes and their coaches to decide how to use the sleeping room."

This reminds me of astronaut training. Sports science, in fact, offers some useful tools for investigating the effects of spending a long period of time under zero gravity conditions, where your body supports very little weight. This causes your muscles to get thinner and your bones to become weak or brittle. Conversely, you could say we 'train' our bodies simply by living under normal gravity.

In order to prevent your body strength from deteriorating in outer space, sports science can determine the optimal load for a healthy body. It can also provide clues as to the best load for elderly people who don't exercise much.

"Because we have such wonderful facilities, our first priority is to support top our athletes. But it would be a shame if we didn't also extend our research efforts to improve the health of ordinary people, and support handicapped people. In today's abundant world, some people forgo food by choosing to fast. Why not come here and try an oxygen fast?"

The earliest life forms are ultra-high-thermophiles bacteria
Earth: farther than the moon

It was raining as I arrived at the Marine Science and Technology Center. Located in Yokosuka City, Kanagawa Prefecture, it is a ten-minute taxi drive away from Oppama Station on the Keihin Kyuko (train) line. This area is far from any industrial or residential district, and seemed to be asleep. Through misty raindrops I could make out an idle crane across the bay.

"Across the bay is a U.S. military base, where we can usually see the USS Kitty Hawk aircraft carrier. Today we can't, so I wonder what's going on."

These were the words of Dr. Kaoru Tsujii, team leader for the center's Frontier Research Program of Deep-sea Environment department. They are investigating deep-sea microorganisms.

"The deep sea is a completely black world that is totally untouched by sunshine. The temperature is between 2 and 4°C, which is lower than a refrigerator. But if you encounter hydrothermal vents down there, the temperature can suddenly rise to 300°C. This is quite literally an 'extreme' environment. From the point of view of deep-sea organisms, of course, it is us who live in a strange environment. For organisms alive during the first phase of life on earth, oxygen was poisonous."

Deep-sea microorganism research is focused on two main areas. The first seeks to understand the mechanism of how they live in order to gain insight on the origins of life itself. If you look at an evolutionary chart, or tree, just off the main trunk (the earliest life forms) are bacteria that live comfortably in extreme heat, with temperatures above 90°C. Life began under these conditions.

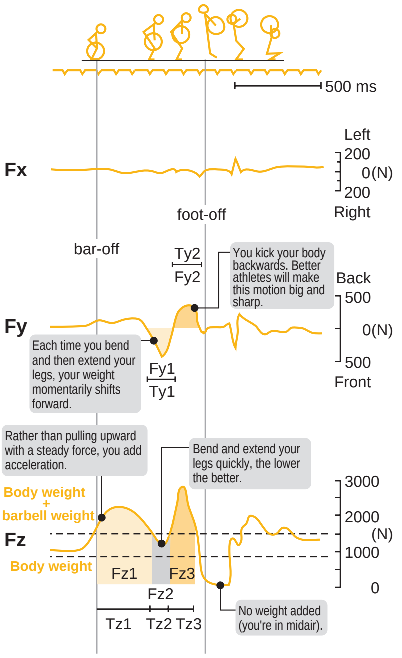
The second focus for research is practical applications. Heat-tolerant enzymes contained in high-thermophiles bacteria, for example, are used in PCR, a DNA augmentation method used in genetic determinations. Researchers are also investigating how deep-sea microorganisms can be used to break down and absorb dioxins and oil dumped into the ocean by an oil spill.

In 1996, 27 years after man landed on the moon, an unmanned underwater research vehicle named Kaiko went to the deepest part of the Earth's oceans, the Mariana Trench. It brought back mud samples from the deepest point of the sea for the first time in history. At 11,000 meters under the ocean there is more than 1,000 kilograms of pressure per square centimeter (an area the size of your fingertip). Because of the high pressure, no one thought living organisms could exist.

"But we discovered around 180 different types of microorganisms living in the mud sample. We also attempted to culture and grow them at our research center and discovered that two types could not survive at pressures of less than 500 atmospheres. Above that pressure, however, they would grow and multiply. Do you think they looked different from other microorganisms,

■ Figure 2 The Reaction of the Floor During the "snatch"

Fx: left and right direction, Fy: front and back direction, Fz: vertical direction



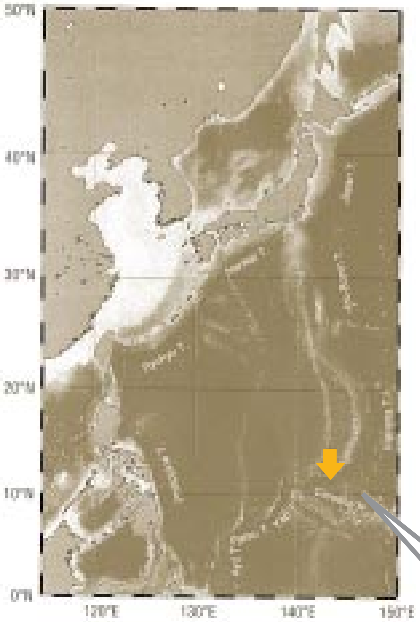
After bending and extending your legs, you slide under the barbell in about half a second.

Weight lifting is not based on raw power alone. It also depends on how fast, soft, and balanced your form is. By combining acceleration with extending your motion, you throw the barbell slightly back on your body. At the same time, you need to quickly slide underneath and be ready for the next balancing point. If you are a beginner, even if you try to imitate these actions using a light barbell, you will not be able to complete them all in half a second.

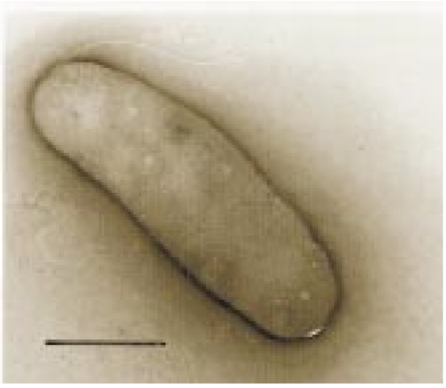
Effective training without movement––The wonders of the nervous system

Mr. Funato and others have performed experiments in which people must remain stationary. From a bed, they do full-strength training on only their right leg. After 3 weeks they examined the left leg, which was not used, and found the amount of muscle was less but the strength was the same. This may be caused by the central nervous system also sending a message during training to the left leg, thereby preventing its strength from declining.

■ Challenger, the deepest point in the Mariana Trench

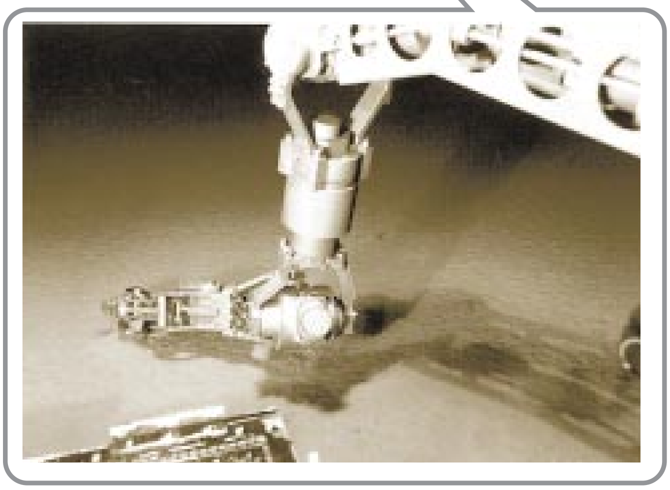


■ An extremely high-pressure bacteria from the Mariana Trench that lives in 1,000 atmospheres of pressure.



Dr. Kaoru Tsujii
Team leader, Frontier Research Program for Deep-sea Environment, Japan Marine Science and Technology Center.

■ Kaiko extracts a mud sample from 11,000 meters under the sea



maybe having a thicker skin or shell? No, they looked the same as all the others."

What is the mechanism behind microorganisms that prefer an ultra-high-pressure environment? You might think they would be crushed or completely destroyed, however, this is only true if you have air inside your body, a characteristic of human beings and fish, which have an air bladder. If an organism consists of only liquid and no air at all, several hundred atmospheres of pressure might compress it only 2 or 3 percent, which isn't a problem. Under such ultra-high pressure, however, enzymes don't function like they do under normal pressure and proteins can actually change. So, how do such microorganisms adapt to this kind of pressure?

"From our research on high-pressure bacteria, we learned certain genes only appear under high pressure, which implies certain proteins can only be assembled under high pressure. But we don't know the function of these proteins in enabling the cell to survive at high pressure. We were the first group to even investigate the mechanism behind high-pressure adaptation and created a new field called 'pressurized physiology.' We recently began holding international conferences on this topic."

In this field, which is closely related to traditional physiology, Japan is the world leader.

Sleeping memories and supercritical water
Returning to your birthplace

Some genes can only be observed under high pressure. Is this unique to deep-sea microorganisms, or do other life forms also have them, perhaps as dormant genes?

"We don't know the answer to this question. But while researching changes that occur to natural yeast and fermenting enzymes at 300 atmospheres of pressure, we recently learned something quite interesting: samples that survived easily absorbed the amino acid tryptophan. This implies that, under high pressure, certain genes appear that can facilitate the absorption of amino acid. We then tried giving tryptophan to normal yeast, which enabled it to survive under such pressures. Even though tryptophan is an important amino acid, our bodies cannot manufacture it themselves. We found a strong correlation between tryptophan and high-pressure survival."

Given this, do deep-sea microorganisms have a gene that enables them to absorb tryptophan, and do they exhibit this ability?

"That's the very subject of our future research. If all deep-sea microorganisms have the gene for absorbing tryptophan, we would conclude tryptophan absorption is essential for survival under high pressure."

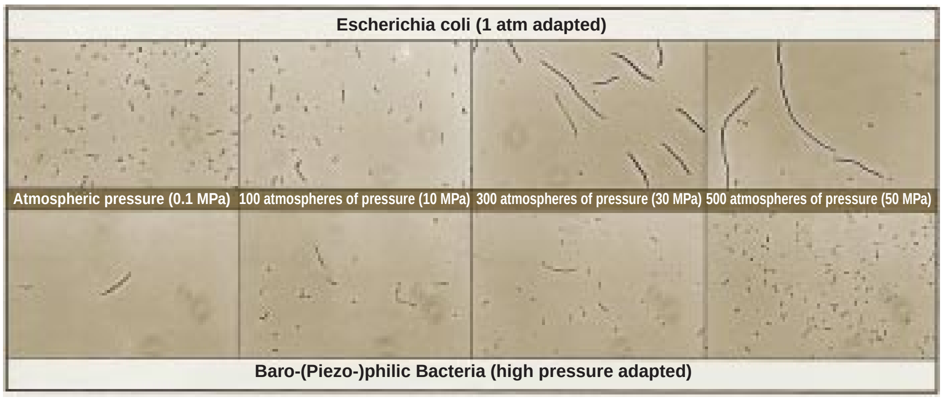
Organisms living in the air and on the earth, including human beings, may also have this gene. The genes that distinguish us human beings comprise only 3 to 5 percent of our entire DNA structure, and we still don't know the purpose of the remainder. Some of them may contain the secrets of how to live

■ An experimental system for investigating deep-sea microorganisms

The only such apparatus in the world is at the Japan Science and Technology Center, whose vast facilities helps researchers recreate deep-sea conditions of extreme temperature and pressure. The apparatus can transfer microorganisms directly from a deep-sea environment, avoiding any intermediate conditions.

■Photograph 1 A microorganism changes shape under high pressure

This one looks like a huge bacillus colon, but actually cannot be separated into smaller pieces because of the effects of high pressure. Bacteria that prefers high pressures will thrive under such conditions.



Photograph courtesy of Japan Marine Science of Technology Center

under high pressure.

"I believe this is quite possibly true. Beyond working with simple bacteria, we have performed pressure experiments on multi-cell organisms, including human skin cells and cultured cells. One of the results was the generation of a material called interleuken, which activates the immune system. We don't know its function with respect to high pressure. Because we can study so many kinds of biological phenomena, there is never a lack of interesting research projects."

Dr. Tsujii spent many years as a researcher in physics and chemistry before becoming a biology researcher.

"I was interested in doing research on supercritical water. If conditions exceed the critical point of more than 220 atmospheres of pressure and more than 374°C, steam is so condensed it makes no sense to try and distinguish between a liquid and a gas. Actually, this phenomenon of supercritical water is what piqued my interest in biological research."

Supercritical water (a liquid) is mainly talked about in the field of chemistry because of its potential to resolve some interesting questions. So why change your research field to biology, or a study of the ocean?

"This has not been proven, but I believe the deep sea contains supercritical water. There is sufficient pressure, and temperatures near hydrothermal vents or underwater volcano are more than 300°C. Three years ago, Dr. Koki Horikoshi invited me to join the Deep-sea Environment department. I was going to accept only if they let me investigate supercritical water. (Dr. Horikoshi is a professor emeritus at Tokyo Institute of Technology, a professor at Toyo University, and Director General Professor at the Deep-sea Environment department, Marine Science and Technology Center.) I was going to mention this during my job interview, however, the first words Dr. Horikoshi said to me were, 'Are you interested in supercritical water, Dr. Tsujii?' Since he is an expert in microorganisms, I was amazed he even mentioned supercritical water."

No organism can survive in supercritical water. But in the surrounding areas, we might discover previously unknown microorganisms with unknown characteristics. It is in this kind of supercritical environment that many people believe life on earth began. Dr. Horikoshi and Dr. Tsujii had a shared research interest in 'supercritical water.'

"In general, biological researchers tend to think in terms of collecting and analyzing databases of information. In physics and chemistry, researchers seek to understand phenomena in terms of a single unifying theory or idea. I am going through a metamorphosis as I become a microbiologist, but I'm still retaining some of the characteristics of a physicist."

Neither gas nor liquid ––– supercritical water

Under high-pressure conditions, the temperature of the phase change from liquid to air increases. But if you exceed a certain point, called the critical point (for water this is 220 atmospheres and 374°C), an air bubble created by evaporation is so condensed we cannot distinguish it from liquid. This is called supercritical liquid (supercritical water). If you dissolve organic matter into supercritical water, lowering the pressure instantly turns the water to gas leaving only the dissolved organic matter. This makes extractions from supercritical water extremely easy, and this phenomenon is used for extraction processes involving food and coffee.