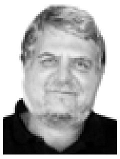
DOI: 10.24425/academiaPAS.2021.139447

To the Limits of Human Endurance – and Beyond?



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The Nimrod Expedition in the Antarctic (1907–1909), led by Ernest Shackleton, Archive of Alfred Wegener Institute for Polar and Marine Research, Wikimedia Commons

We are setting new sports records and conquering space, but are helpless against climate change and new viruses. **Prof. Andrzej W. Ziemba** talks about the human body's abilities.

Do we know the limits of human adaptation to natural conditions?

ANDRZEJ W. ZIEMBA: This question makes me think of the excellent book *Granice przystosowania* [Limits of Adaptation], written by the prominent Polish physiologist Stanisław Kozłowski, which largely answers your question. Generally speaking, the human body is adapted to life in a relatively narrow set of environmental conditions, such as temperature, pressure, the concentration of gases in the air, and so on. This results from the history and evolution of the *Homo sapiens* species. Many other animals have a lot greater capabilities in this respect and can receive a much wider range of stimuli from their external environment.

Neutral buoyancy pool, NASA Neutral Buoyancy Laboratory, Johnson Space Center in Houston, Texas, Wikimedia Commons

Perhaps let's start by explaining how the human body functions. Here, it should be stressed that it is the interaction between the organism and its internal environment on the one hand and the external environment on the other that forms the basis for adaptation. Such mechanisms provide the basis for Hans Selye's theory of stress. It posits that a stimulus from the environment (such as a change in the external temperature) triggers many reactions in an organism that result in its adaptation. The functioning and adaptation of the human body are based on homeostasis, which is a process aimed at maintaining the stability of internal variables. This is possible due to feedback loops, which trigger the reactions of individual body systems depending not only on the body's own needs, for example in response to a meal or to exercise, but also the needs independent of the body, such as the aforementioned adaptation to changes in the external temperature, pressure, and other conditions in the external environment that affect us.

Do we have the ability to push the boundaries between our capabilities and environmental conditions?

Thanks to intelligence, our species has developed methods to circumvent the barriers that nature imposes on our physiological capabilities. The simplest example is defense against extreme temperatures. In theory, humans can function within a relatively small range of ambient temperatures. That's why we have mechanisms for regulating heat retention and loss. However, our civilization, whose objective is to increase the comfort of life, has allowed us to develop methods to facilitate survival in conditions beyond our normal adaptive capabilities. Such methods include heated houses, clothes suited for very different types of weather, air conditioning, and so on. In addition, pushing the limits of these capabilities is often associated with the drive to pursue knowledge and the dream of breaking barriers or making discoveries. That's why we continue to test our abilities by traveling to the most inaccessible places characterized by extreme conditions, such as the depths of the ocean, outer space, and the inside of volcanoes.

People who take up such challenges give us glimpses into the human body's chances of survival in extreme circumstances. The scientific literature describes many cases of unimaginable adaptive capabilities that allowed humans to survive in extremely harsh natural conditions. For instance, descriptions of human survival in extreme temperatures are simply fascinating – such as the great polar expeditions

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mounted by Robert Falcon Scott, Roald Amundsen, and Ernest Shackleton more than 100 years ago. In particular, we may still have difficulty believing that 28 members of the latter expedition miraculously survived around a year in extremely adverse conditions in Antarctica. The story of Jean-Louis Étienne, the first man to reach the North Pole solo, is equally astounding. Hauling a sledge that weighed 50 kg, he covered 1,100 km in 63 days in temperatures ranging from −12°C to −52°C. Étienne, being a doctor himself, kept a detailed record of the changes his body underwent, which led to many important conclusions about the physiology of survival.

To stick just with the topic of extremely cold temperatures, history provides us with cases of people who survived hypothermia, which is a state in which the body temperature falls below the normal range. Such survivors have included some of the soldiers from Napoleon's army during its retreat from Russia in the winter of 1812, as well as some of the passengers of the Titanic, who spent hours in the icy water, waiting for help. The lowest recorded body (rectal) temperature seen in a human hypothermia survivor is 13.7°C (the normal rectal temperature is 37.6°C). The survivor was Anna Bågenholm, a Swedish national who suffered a skiing accident in 1999 that left her trapped under a layer of ice for 80 minutes in extremely cold water.

What about extremely high temperatures?

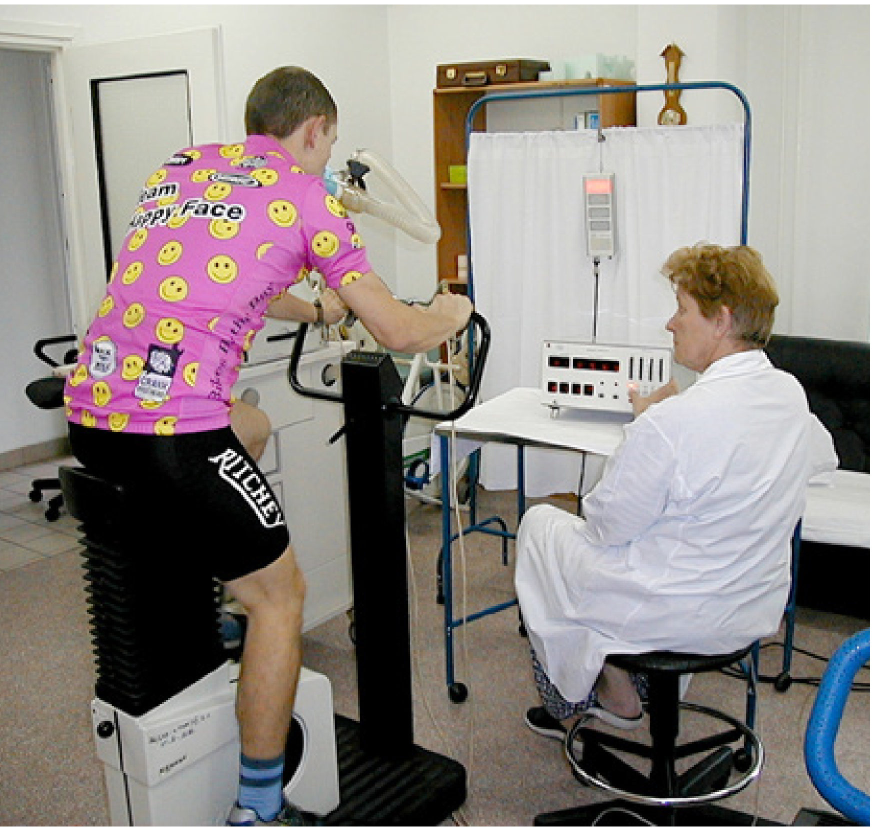
Human tolerance for high-temperature surroundings is generally much lower than for sub-zero deviations from the norm and requires special conditions. Famous experiments in this field were conducted in the 18th century by a British physician named Charles Blagden. He exposed himself, as well as his coworkers, a dog, and a raw steak to very high temperatures. It turned out that even when the steak was already cooked, the participants were still able to survive in a heated room in excess of 120°C. Such experiments were replicated, and keeping the air dry while its temperature remained hot was the important element that allowed the participants to survive. In that case, they developed no skin burns, and their bodies were able to properly defend themselves against the heat by sweating.

However, we must remember that the body's mechanism of disposing of excess heat is not without cost. Its abnormal activation may lead to dehydration and, by the same token, to the loss of valuable electrolytes, especially sodium. In extreme situations, this may cause the body to overheat, resulting in death from hyperthermia. Of course, sweating is a process that accompanies us every day. Each day, the human body loses about 2.5 liters of water through sweating and urination, and we replenish fluids by drinking. The literature describes cases of losing of up to 14 liters a day in very high temperatures. Even during a 90-minute game played in thermoneutral conditions, soccer players can lose up to six liters of water. These lost supplies must be replenished on an ongoing basis through drinking.

It's therefore a lot more difficult for humans to survive without water than without food. Hunger strikes don't last more than three weeks, because that's when dangerous, life-threatening symptoms start. Without water, humans can survive for no more than three days. This is something that must be borne in mind, not only when we protect our bodies from the summer heat, but also in the face of imminent climate change, as water shortages turn into a social and political problem.

Athletes in a variety of sports keep improving their performance. Could this also mean that we are pushing the limits of human endurance?

Absolutely. Increased physical activity requires most of the body's systems to work more intensively, starting with the respiratory and circulatory systems, mobilization of energy reserves by the endocrine system, and so on. Reactions of the human body to exercise in various conditions (for example, at work or in the case of cardiovascular disease), as well as its effects on other processes, such as aging, are the focus of our research interests. Many of the results once obtained in the Department of Applied Physiology at the Mossakowski Medical Research Institute, Polish Academy of Sciences, are now knowledge that can be found in textbooks. Currently, we are working with the National Center for Sports Medicine (COMS) on what is referred to as overtraining syndrome, which affects some athletes. It is an evident breakdown of the body's capabilities to adapt to increased physical activity. It manifests itself in a sudden deterioration of an athlete's exercise capacity and sports performance.



A stress test performed in the Mossakowski Medical Research Center, Polish Academy of Sciences

There's also another interesting topic, namely ultraendurance. It's now very popular and pertains to multi-day sports competitions, such as trail running in the Alps and the Ironman triathlons. These are no longer simply marathons that involve running 42 kilometers and 195 meters. Humans keep pushing the limits of the body's adaptive capabilities and are organizing such grueling competitions as ultramarathons (runs longer than the traditional marathon length of 42.195 kilometers – editor's note) in Death Valley in California (217 km at a temperature of 50°C), or the Sydney to Melbourne ultramarathon, which took place in the 1980s. In the latter case, I remember a 61-year-old farmer named Cliff Young who finished the 875 km race in 5 days, 15 hours, and 4 minutes. One of the reasons why he succeeded was that, unlike other participants, he took no breaks to sleep. These are all spectacular examples of stretching the limits of human physiological capabilities.

Such physical effort is associated with unimaginable energy expenditure. Examples from the literature mention up to 24,000 kcal per day (to put this into perspective, the energy expenditure of a person leading a sedentary lifestyle rarely exceeds 3,500 kcal). Despite special nutrition strategies, including high-energy bars, there's inevitably an energy deficit. The body's stored fats and carbohydrates, which are basic sources of energy, becomes exhausted, and the body starts burning proteins for energy, including the proteins that make up different structures. In other words, the body begins to eat itself. This is regarded as the most serious negative effect of excessive exercise. In extreme cases, it can be compared to the state of the body after debilitating starvation or a life-and-death struggle against cancer.

What are the things that the human body cannot handle?

In my opinion, the human body doesn't have sufficient capacity to adapt to ongoing climate change and other global challenges, such as health crises. We don't have properly developed mechanisms to cope with heat waves, water shortages, or novel viruses and bac-

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An astronaut on the Moon

teria carried by invasive species from various regions of the world. The balance between humans and the environment has been severely upset, and restoring it will be very difficult. More affluent societies can resolve the problem of high temperatures by using air conditioning. However, this is an *ad hoc* solution that further drives high energy consumption, which is after all the underlying problem here. Likewise, we can't function without water, which is the source of all life. Until recently, our civilization did quite well in protecting human adaptive capabilities from harmful stimuli from the external environment. At some point, however, a certain point was crossed, and the protection of adaptive capabilities will no longer be possible. This is happening now.

What should we focus on to improve the defense capabilities of the human body?

Scientists are currently working on improving the human body's adaptive capacity in the context of its resistance to bacteria and viruses. Both to those that already pose a threat to us and the ones that we are not aware of yet. Nature forces us to face new challenges, not just those related to climate change. A case in point is the ongoing COVID-19 pandemic. The distance between man and wildlife has been drastically reduced as a result of human activity. This situation creates threats which exceed our adaptive capacity and for which we are not prepared. This is one of the global challenges concerning the endurance of the human body. Many laboratories around the world are working on methods of protection against new viruses. But this task is not easy, because we don't know most of these threats yet.

What aspects of the human body's limits instill great emotions among scientists?

From my perspective as a physiologist, the most inspiring research pertains to the relocation of some portion of humanity to other planets. I think that it's absolutely possible to create such conditions on other planets so as to enable a small group of settlers to live there. Of course, this would necessitate artificially creating conditions similar to those found on Earth: temperature, pressure, and breathable air. This would be possible for a small number of such brave settlers. However, I'm skeptical about the possibility of populating selected planets on a larger scale. Life on Earth developed the adaptation mechanisms we have today, which is how our bodies function today. One of these mechanisms involves functioning under certain gravitational conditions.

We should remember that astronauts who experience weightlessness, or a state of zero gravity, for prolonged periods, also experience many adverse and harmful changes in the body. Scientific records of these phenomena are abundant and come not only from studies of astronauts during and after space flights, but also from research conducted on Earth. For example, space-like conditions can be achieved in a deep swimming pool. NASA has such a 12-meter-deep pool in Houston, where it conducts training and tests.

> Pushing mankind's limits is often associated with the drive to pursue knowledge and the dream of breaking barriers or making discoveries.

The impact of the lack of gravity on the body can also be studied in a person who simply lies down for a long time (much longer than the usual time of rest). The changes that occur in the body are almost the same as those observed during flights outside the sphere of Earth's gravity. A person lying down experiences the absence of gravity because there is no exercise and no pressure on the long bones. If such a situation continues for a long period, it entails serious physiological consequences for all the systems of the body: muscle and muscle strength decrease, glucose tolerance becomes impaired (a condition similar to prediabetes), loss of calcium increases (which increases bone fragility), and so does the loss of electrolytes, exercise capacity decreases, and so on. We have done research on this subject at our institute, in collaboration with NASA.

INTERVIEW BY **JUSTYNA ORŁOWSKA, PHD**