Man in Extreme Environments

ALF O. BRUBAKK, M.D., DR.MED.

BRUBAKK AO. *Man in extreme environments.* Aviat Space Environ Med 2000; 71(9, Suppl.):A126–30.

Humans have demonstrated the ability to live and work in many adverse environments. Many examples demonstrate that our understanding of humans' ability to adapt to extreme environments is limited, but it is reasonable to assume that the main problems in space exploration will be psychological and social. It is argued that polar expeditions of an earlier age are a better model for space exploration than confinement studies or Antarctic overwintering. Some aspects of the reason for the success of these expeditions are discussed and the lessons that can be used are pointed out.

Keywords: extreme environments, polar expeditions.

"EVERYONE IS AN EXPLORER. How can you possibly live your life looking at a door and not go open it?" (18).

Space has been termed the last frontier. With the establishment of the International Space Station, we are starting a new era of exploration by humans that is similar to the exploration of previous centuries, where large white portions of the map were explored. This brief review will look at some of the experiences both from these explorations and from the people who have lived in the arctic to see if there are some lessons that we may use in our future space exploration.

There is now considerable experience in going into space for short periods of time, but relatively few have stayed there for many months. However, a long spaceflight is not the same as a short flight, and a trip to Mars or Europa is quite different from staying in Earth orbit, even for long periods of time. There are possibly less physiologically deleterious effects of long-term stays in space than was earlier predicted by the medical establishment and the main problems encountered by humans in space may be psychological and social.

Extreme Environments

Humans have been able to survive and function in many extreme environments. An extreme environment can be defined as an environment where basic needs, like the acquisition of food, shelter and protection, require an extraordinary effort. One particular aspect of these environments is that errors in judgment and behavior can have serious, even fatal, consequences. An overview of some of these environments, both man-made and natural, can be seen in Table I. Several more can probably be added, but this demonstrates that many of the environmental conditions encountered on Earth can also be encountered in space, although to a much more extreme degree.

Humans developed in the temperate zones of the Earth and only moved into the arctic about 5000 yr ago. The lack of body hair offers little protection from the cold and therefore the ability to survive is critically dependent on the ability to adapt to the environment and to devise protective strategies. There are obvious physiological limitations to one's ability to withstand extremes in environmental stresses. However, again and again it has been demonstrated that humans are able to withstand extremes initially considered not to be compatible with survival. One example is reduction in oxygen tension. Physiologists assumed that humans could not ascend the highest mountain on Earth, Mt. Everest, without using supplementary oxygen (8). At this height (8850 m) the oxygen tension is approximately 5.7 kPa or about 25% of that at sea level. Still, in 1978 two climbers, Reinhold Messner and Peter Habeler, climbed the mountain without using oxygen, and since then a large number of mountaineers have done this (9). This is even more impressive when one knows that at these oxygen tensions, the maximum oxygen uptake is nearly the same as the basal oxygen uptake (8). However, this feat is not possible without adequate adaptation, demonstrating that the knowledge and understanding of the physiological response to heights is vital in ensuring success.

Another example is breath-hold diving to great depths. Physiologists determined that it would be impossible to go deeper than about 70 meters of sea water (msw), because at that depth, the lungs would be fully collapsed (1). However, several divers managed to break this barrier and the current world record is in excess of 130 msw, forcing the physiologists to modify their theory and increasing our understanding of human physiology (6).

These examples underscore the fact that our understanding of the limits to one's adaptability to strange and dangerous environments is limited. At the beginning of entering space, many authors pointed out the possible adverse health effects of space. Subsequent experience has taught us that humans are probably able to live and work in space for several years (15). We are probably well served to admit our lack of knowledge

From the Department of Physiology and Biomedical Engineering, Medical Faculty, Norwegian University of Science and Technology, Trondheim, Norway.

Address reprint requests to: Alf O. Brubakk, who is Professor of Environmental Physiology, Dept. of Physiology and Biomedical Engineering, Medical Technology Centre, N-7005 Trondheim, Norway.

TABLE I. ENVIRONMENTS AND CONDITIONS.

Primary Natural	Primary Man Made	Conditions	Environment
X		Decreased temperature	Arctic/ Antarctic
X		Increased temperature	Tropics
X	X	Reduced pressure	Altitude/ flight
	X	Increased pressure	Diving
X		Reduced gravity	Space
	X	Increased gravity	Flight
X		Decreased oxygen content	Altitude
	X	Increased oxygen content	Diving
	X	Changed inspired gas composition	Diving
X		Lack of water	Desert
X		Lack of food	Anywhere
X		Increased radiation	Space
X	X	Isolation	Arctic/Space

and recognize that theoretical assumptions have to be checked against facts.

Adaptational Strategies

The possibilities for physiological adaptation to an extreme environment are limited, and as the example from altitude demonstrates, in some cases may be crucial.

Such physiological adaptations are lost when the individual returns to more "normal" environments. The individual or the group may, however, adapt to the environment through a series behavioral strategies that overcome the lack of physiological adaptation. The importance of these behavioral strategies cannot be overstated; these are, in many ways, much more important than the availability of proper tools. Due to our ability to produce increasingly better tools and equipment, we tend to forget the experiences both of people currently living in the arctic and those from previous expeditions.

Man has lived in the polar regions for about 5000 yr or about one-tenth to one-twentieth of the time humans have been on Earth. During this rather short time span, humans have been forced to develop a number of strategies to live and survive. The lessons from the people who had been there was not lost on the successful early explorers of this region, as to a large extent they used methods and equipment derived from the Inuit.

The special environment in this region formed both the behavior and the strategies. Some Inuit survival strategies include: a) know your environment; b) be familiar with the effect the environment has on you; c) use only adequately tested equipment; d) do not take unnecessary risks; e) do not focus attention on a single activity; f) cooperate; and g) when in trouble, try lateral thinking. Some of these points are self-explanatory, and I will only focus on a few of them

An Inuit will not lie or steal. This has nothing to do with any moral principle, but is simply caused by the fact that incorrect information or lack of proper tools when needed may be fatal. The survival of the group is regarded as the important goal and Inuits will not perform stupid stunts that will endanger them. Inuits will share and expect that others will share as well. An anecdote illustrates the importance of group coherence: A man is scolding his wife because she has been a bit free with her favors to another man. The other wives objected to this and pointed out to the man that if he had scolded her before she had performed the act, this would have had the purpose of preventing it. Now, however, it only contributed to disrupting the group and was totally unproductive (4).

In extreme environments, the ability to put the group first is of utmost importance. However, these environments also require that every member of the team is able and willing to take care of themselves and that they have enough knowledge, experience and self-reliance to question the judgment of the leaders, if necessary. An example of the importance of this was demonstrated in the recent disaster on Mt. Everest, where 11 people died (17). A significant contribution to this was apparently the action of the two very experienced guides, who decided, against all experience, to press on to the summit even after it was clear that doing so would significantly reduce the chance of returning to base before dark. It is very difficult psychologically to stop short of your goal, even if that is the sensible thing to do. That is made more difficult by our cultural heritage, telling us that to be second is failure.

Too much self-reliance is also quite dangerous in these environments. This has been demonstrated by the wish of technical divers to go to ever increasing depths. At great depths (beyond 180 m) there is a considerable risk of developing serious central nervous symptoms, the so-called High Pressure Nervous Syndrome. Disregarding these risks has been fatal (7).

Long Expeditions

The use of analog environments is important for planning long term exposure to space. Examples of these include long submarine voyages or stays at Antarctic stations. These environments may be relevant for a prolonged stay at space station, but may be less so for long expeditions to other planets. Even with all our planning and information from unmanned robots, these expeditions will carry an important element of surprise, of the risk of encountering totally unexpected problems. Many of the expeditions to the arctic in the past went out with only limited knowledge about what they were facing. There were few or no maps, there was no communication with anybody and there was no chance of resupplying or getting help if anything went wrong.

As an example of this, I will discuss two such expeditions in some detail, namely the polar drift by the "Fram" from July 1893 to August 1886 and the Trans-Antarctic expedition of the "Endurance" which lasted from December 1914 to May 1916.

The Fram Expedition

"At all times, the north has been of considerable interest to man. If the south has attracted the will to gain riches, the north has above all attracted the imagination." Thus starts the introduction of the application by Fridtjof Nansen for financing a drift over the polar

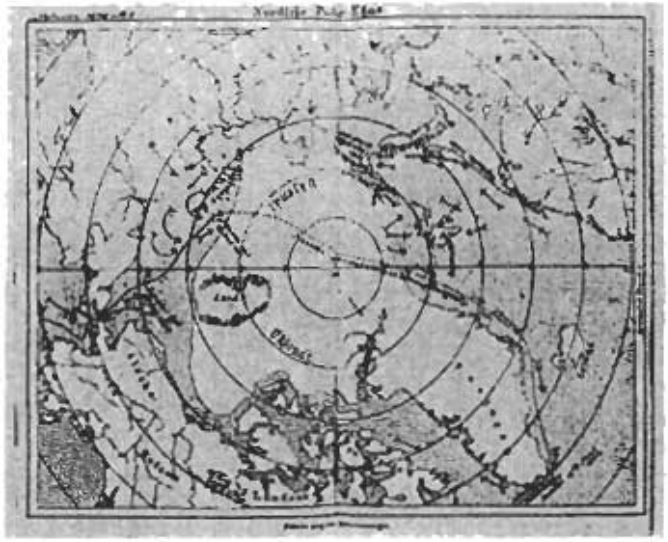

Fig. 1. Map of the North Polar Basin accompanying Nansen's application for funding of the polar drift (12).

basin (12). Fig. 1 shows the map of the northern regions that Nansen submitted with this plan for drifting over the North Pole. Of particular importance is to note the large white area in the middle of the map termed "ukjendt" (unknown). It is also worth noting the point marked just south of the North Pole (on the left side of the map), at about the 85th parallel, where the ship, *Jeanette*, sank. Note also the line going across the polar basin to the south coast of Greenland where some tools from this ship were found 4 yr later, indicating the possible route the wreckage could have taken. This find was the only piece of evidence presented by Nansen to indicate that there might be a polar current, even if there were a number of other indications. In order to study this area he proposed to use a novel and fully untested method, namely to design a ship that would not be forced down by the ice, but would slip on top of it. This ship was to be equipped to allow 12 men to live there for the 5 yr a drift-through over the pole might take.

Even if there were some acknowledgment that Nansen's theories may have had some merit, nearly all experts stated that the method he proposed to use was impossible (3) and that the expedition would end in disaster. The peer review of his proposal was quite negative, which Nansen also describes in detail in his book about the expedition (14). It is perhaps also worth noting that Nansen's own qualification in the arctic when proposing this plan, which was termed the most "hazardous and ambitious plan ever presented to the Royal Society," was an expedition on skis across Greenland.

In spite of all this, Nansen received support for his expedition, mainly from the Norwegian government. It seems clear that the reason he was able to do this had much to do with his ability to create enthusiasm and a feeling of national unity toward a common goal.

One reason for Nansen's success was his ability and willingness to learn from the indigenous people of the arctic and from earlier explorers. After the Greenland expedition he spent a winter with the Inuit there and even wrote a book about them (13). He used all this knowledge when developing the equipment that was to be used on the expedition. One good example is the selection of food to be carried. One serious problem on many previous arctic expeditions had been scurvy, which is caused by the lack of Vitamin C. At the time, this was not known, but Nansen knew from studying the food of the Eskimos the importance of plants and vegetables and the importance of proper drying and conserving of meat and fish. He also carried a large quantity of cloudberries, a very rich source of Vitamin C already used by the Vikings on their long sea voyages. He also knew the importance of supplementing the stores with fresh meat, another source of Vitamin C usually not recognized.

Another important lesson is that Nansen chose to work with the elements, not against them, by drifting with the currents. However, it soon became clear that Nansen's theory about a shallow polar basin and the polar currents was not correct, and that Fram would never get anywhere near the North Pole. He then decided, with one companion, to abandon the ship and to try to reach the pole by using dogs and skis. In this he showed his gift for improvisation, in particular in constantly redesigning skis, sledges and equipment to make them more efficient.

The ship was equipped with a large number of tools for producing many kinds of equipment. A carpentry shop and a machine shop were established and some of the crew worked as cobblers and sailmakers. Thus, everybody had his own area of activity.

The planning was obviously a very important part of the success of the expedition. It is important to note the extraordinary length to which Nansen went in considering the details. In this expedition, preventing scurvy was obviously of major importance. Nansen certainly knew nothing about what caused this disease, but he had learned from previous expeditions what food to use to prevent it. He used well-tested equipment, but was not afraid to improvise when necessary. During the expedition every man had a job, and care was taken to ensure that it was done properly. Some pressure was put on the men to exercise, for instance, but is noteworthy that the men were usually left to themselves to determine when and how they would do so after their duties.

The Transantarctic Expedition

This expedition was planned by Ernest Shackleton to cross the Antarctic on foot using dogs and motor-sledges. The expedition never got further south than the 77° south, as the *Endurance* was caught in the ice. The ice proved too much for the *Endurance* which eventually sank and the crew was forced to abandon ship. They spent 170 d drifting on an ice floe without adequate shelter and food, followed by 7 d in an open boat at the beginning of winter before reaching land on Elephant Island. Only a week after reaching land, Shackleton again set out with five companions in an open boat to reach South Georgia Island. After 17 d and crossing 800 mi of some of the most stormy oceans in the world, they reached land, but on the uninhabited side of the island.

Shackleton and two companions then crossed the island walking for over 30 h over unknown terrain at heights up to 10,000 ft before reaching a whaling station. In the end, all of the crew was rescued (10).

This remarkable feat was mainly due to Shackleton himself and clearly demonstrates the importance of leadership in determining the outcome of the expedition.

Shackleton had shown some of his important leadership abilities on a previous expedition, where he had the turned back only about 100 mi from the South Pole in order to save himself and his companions. When they were first stuck in the ice it was noted that: "he did not show outwardly any sign of disappointment; he simply told simply and calmly that we must winter in the Pack, explaining its dangers and possibilities; never lost his optimism, and prepared for winter" (2).

Later, when they had to abandon ship and start their long travel toward land, he never showed any lack of optimism or indication that they would not make it, in spite of inadequate provisions and equipment. It is quite characteristic that even if there was a strict allowance for personal belongings, Shackelton allowed one of his men to bring along a banjo for the entertainment of the others. It is also worth noting that when issuing sleeping bags to his crew, the best bags all went to the sailors, while the officers had to make do with less substantial bags. Shackleton always considered the morale of the men more important than practical necessities.

During the whole trip to safety, Shackleton's companions note that his optimism and unflagging consideration of his men was the single most important contribution to their success.

Shackleton had a totally different personality than Nansen. He made a point of being "one of the boys" on many occasions, without ever losing his authority, while Nansen always kept his distance. The importance of different personalities for different problems is nicely pointed out by Cherry-Garrard who states: "For a joint scientific and geographical piece of organization, give me Scott. For a dash to the Pole and nothing else, give me Amundsen. If I am in a devil of a hole and want to get out of it, give me Shackleton every time " (5).

Selection of Participants

From the accounts of different expeditions in the arctic, it seems quite clear that most successful arctic explorers were more concerned about the practical and social skills of their companions than with their physical performance.

When selecting participants for his expedition, Shackleton looked for people with multiple skills and with the ability to get along with others. He looked for people with optimism, patience, idealism, physical endurance and courage (16). It was noted that the ability to contribute to the social activities was considered important.

According to Nansen, there was no lack of applicants for his expedition. In his books he does not give any indication on how he selected his crew, apart from the fact that he insisted they be strong and healthy. Still, from the accounts of this expedition, there is no indication that there were any serious inter-personal problems, apart from those caused by Nansen himself. His decision to leave Fram actually improved the social climate.

Sometimes, even differences in national traits were considered important for polar expeditions. The U.S. Navy, circa 1870, wanted: "Single men, perfect health, considerable strength, perfect temperance, cheerfulness, ability to read and write English, prime seamen of course. Norwegians, Swedes and Danes preferred. Avoid English, Scottish and Irish. Refuse point blank French, Italian and Spaniards " (11).

Lessons for the Space Endeavor

It is the hypothesis put forward in this review that space is another extreme environment where lessons from extreme environments on Earth can be useful.

One lesson that can be learned, both from the Inuit and from successful expeditions, is to understand and use the environment to your advantage and to work on the premises of that hostile environment. In discussion of longer trips in space, much emphasis has been put on the problems; perhaps it is worth considering some of the possibilities of this environment.

The success of Nansen's expedition was partly due to the fact that all men had their own duties and expertise, and to a large degree they were able to determine their own schedules. None of them were scientists except Nansen himself, but it was quite clear to them that this polar drift was in essence a scientific expedition and that everyone had to contribute toward that end. They showed a great deal of ingenuity in designing their equipment, while all the time using the knowledge and experience of the people who had been there before.

There was no such common goal in Shackleton's expedition, but when disaster struck, the ability of one leader to have everybody pull together probably saved them.

The expeditions of the past were often conceived and planned by one or a few individuals who had tight control over their program. This is obviously not possible in planning a long term space mission, but the importance of delegating responsibility, both for planning and execution, to those who are actually in the field is quite clear.

A large number of selection criteria have been used in the space program and in other programs like wintering in the Antarctic. These selections are probably reasonably good for selecting out those most unsuitable, but are probably less so in determining who will succeed. Many of the participants of past expeditions would probably not have qualified, if such criteria had been in force. Perhaps less time should be spent in testing the individuals and more time in testing the groups that will live and work together. Perhaps of even more importance is to make sure that those who make the decisions actually understand the problems that the expedition members may encounter. To my knowledge, no one has suggested testing the testers and managers responsible for making the decisions.

Isolation studies have been performed for studying

the effect of close confinement for long periods of time. These studies, however, lack the important elements of danger, unpredictability and lack of communication, which probably contribute significantly to the stress of a real expedition. Thus, isolation in remote areas without direct contact with the "outside" would seem to be a better model.

One of the ongoing arguments about the space program is the question, "Why endanger people when unmanned robots can tell us everything we want to know?" Perhaps we can learn something from Nansen. When faced with the argument "What is the point in fiddling along in the ice up there? There is nothing but ice, of no importance to mankind," he answered: "In order to say that, we already have to know these areas, which we do not. What we do know about these regions indicate that further knowledge may be of immeasurable importance to mankind." He also discussed the use of "robots," in his case hot-air balloons, for studying these regions. He writes: "A larger scientific gain can only be had by long term studies on the ground" (12). Subsequent developments have shown that he was right; today the importance of understanding the currents of the arctic for predicting both long and short term weather on Earth is accepted. It is true that the robots of today are vastly superior to anything developed during Nansen's time. However, one's ability to make errors, which sometimes gives totally unexpected results, and the fact that one sometimes does not follow rules and acts without knowing all the facts, may be quite advantageous in many situations.

Another factor easily overlooked is the importance of generating enthusiasm. Nansen's expedition generated an enormous response in Norway and was, without doubt, partly responsible for the increase in Norwegian self-reliance leading to the separation of Norway from Sweden in 1905. In view of the enormous importance of science and technology in our world, space exploration can be used as a tool to generate enthusiasm for science.

Both the people living in the arctic and the long expeditions of the past have demonstrated that people are capable of living and working together under very adverse conditions. These lessons can help us when we are planning for travel outside the limitations of our own planet. If humans do not learn from history, we are bound to repeat our mistakes.

ACKNOWLEDGMENTS

At this meeting I met Jack Stuster and was made aware of his book "Bold Endeavors," that in a much more thorough way has explored the similarities of space travel and expeditions of the past. His contribution to clarifying my own thoughts is gratefully acknowledged.

The comments and suggestions of Olav Eftedal are greatly appreciated

REFERENCES

1. Agostini E. Limitations to depth of diving: mechanics of chest wall. In: Rahn H, Yokoyama T, eds. Physiology of breath-hold diving and the Ama of Japan. Washington, DC: National Academy of Sciences, 1965; 139–45.
2. Alexander C. The Endurance. Shackleton's legendary Antarctic expedition. London: Bloomsbury, 1998.
3. Anonymous. How can the North Polar regions be crossed? The Geographical Journal 1893; 1–32.
4. Birket-Smith K. The Eskimos. London: Methuen, Co. Ltd., 1938.
5. Cherry-Garrard A. The worst journey in the world. London: Constable, 1922.
6. Ferrigno M, Lundgren CEG. Human breath-hold diving. In: Lundgren CEG, Miller JN, eds. The lung at depth. New York: Marcel Dekker Inc., 1999; 529–85.
7. Gilliam B. Deep diving. San Diego: Watersport Publishing Inc., 1995.
8. Heath D, Williams DR. High-altitude medicine and pathology. Oxford: Oxford University Press, 1995.
9. Lagercrantz D. Gøran Kropp. Stockholm: Bokfoerlaget DN, 1997.
10. Lansing A. Endurance. Shackleton's incredible voyage. New York: McGraw-Hill Book Company Inc., 1959.
11. Maxtone-Graham J. Safe return doubtful. London: Patrick Stephens Ltd., 1989.
12. Nansen F. Plan til en ny polarekspedition. *Naturen* 1890; 4: 65–92.
13. Nansen F. Eskimoliv. Kristiania: H. Aaschehoug Co., 1891.
14. Nansen F. Fram over Polhavet. Kristiania: H. Aschehoug Co., 1897.
15. Nicogossian AE, Huntoon CL, Pool SL. Space physiology and medicine. Philadelphia: Lea & Feibiger, 1994.
16. Shackleton E. The heart of the Antarctica. London: William Heineman, 1909.
17. Simpson J. Dark shadow falling. London: Vintage Random House, 1998.
18. Vesilind PJ. Why explore. National Geographic 1998; 193:41–5.