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Critical Literature Review

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Food for Man-hauling and other Extreme Physical Activities in the Antarctic

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Abstract

The explorers of the Heroic Age and earlier understood the need for a well balanced diet with additional calorific value and nutrients for traveling and exploring the Antarctic. They went to considerable lengths to test and modify diets that best suited man-hauling with a focus on reducing weight to the bare minimum to extend range. The same constraints affect man-hauling today, and in addition there is now greater understanding of the other foods that the human body needs to achieve high performance in an environment that test the human body's resistance to extreme physiological stress.

Modern explorers consider the impacts of severe exercise, nutrition, hypothermia, hypoxia, sleep deprivation, and dehydration when planning trips in the Antarctic. These factors affect the amount of food carried and the performance of the individual and are critical to achieving maximum distance.

Inputs include daily food intake of fats carbohydrates, and protein along with water, warmth, oxygen, and sleep. Deficits in any of these inputs start to impact human performance and the cumulative effects over extended periods of time can lead to disaster. Understanding the effects of deficits and the interrelationship between each input can help the explorer cope in the field and develop strategies for survival when things go wrong.

The science of nutrient balance, dehydration, hypoxia, and sleep deprivation are relatively new. Studying the effects of these inputs can eliminate constraints on exploration and assist our understanding of where exploration went wrong.

Food for Man-hauling (Nourishment During Extreme Physiological Stress).

> *The 1910–1913 Terra Nova Expedition to the Antarctic, led by Captain Robert Falcon Scott, was a venture of science and discovery. It is also a well-known story of heroism and tragedy since his quest to reach the South Pole and conduct research en route, while successful was also fateful. Although Scott and his four companions hauled their sledges to the Pole, they died on their return journey either directly or indirectly from the extreme physiological stresses they experienced. One hundred years on, our understanding of such stresses caused by Antarctic extremes and how the body reacts to severe exercise, malnutrition, hypothermia, high altitude, and sleep deprivation has greatly advanced. On the centenary of Scott's expedition to the bottom of the Earth, there is still controversy surrounding whether the deaths of those five men could have, or should have, been avoided.*
> *(Lewis G.Halsey and Mike A. Stroud , 2012. P1)*

This paper reviews the literature available to athletes when planning food requirements for exploration and adventure in the Antarctic. **Food for the body not only includes what is eaten, but also fluids (water), oxygen, sleep, and warmth - all necessary inputs to keep the human vessel operating in a consistent and reliable manner.** The Antarctic is an extremely hostile environment that is unforgiving of simple mistakes, and it is remarkable that so few of the early explorers died in the Antarctic. Had Scott's pole party returned safely to Hut Point and then overcome their injuries, it is unlikely that we would have the depth of focus on their trip that we still have today. Athletes would not be lining up to attempt to repeat the polar journey. Historians and journalists would be writing different stories. Our knowledge of food in extreme environments would have been learned elsewhere with another team of intrepid explorers falling under the sword of the writers pen for not knowing what they didn't know. (Reaney, R. 2009)

The long endurance man-hauling trips from the heroic age provide good case studies. There are three constraints to consider: time, distance, and speed. See fig. 1.The distance to the pole was close to maximum achievable given the time available, and the speed at which they could travel. The distance could have been reduced by starting closer to the pole, but this was not practical. The time available could be increased by starting earlier and finishing later but again not practical with spring and autumn weather pattens. This leaves speed as the only constraint that could be managed to ensure success.

Speed (miles per day) as a constraint can be maximised by:

- increasing strength to pull - requires more energy and more food,
- increasing hours per day spent hauling - more energy and more food,
- reducing weight to be pulled - carry less food. Lighter weight camping equipment,
- sledge adaptions - change runner selection to match surface conditions - technology.

Caching food depots along a return journey with support from other teams reduces the weight of food to carry and effectively increases the range that could be attempted. At some point food always becomes the one limiting constraint that must be managed.

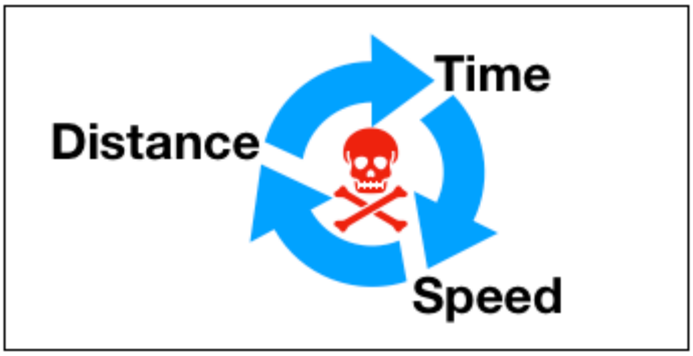

Fig. 1. Time, Distance, and Speed - Man-hauling in the Antarctic.

Running low on any of these constraints results in failure and ultimately death. Today's explorers have the luxury of calling up the support team to fly in more food. Explorer Ben Saunders attempted to complete Captain Scott's failed 1912 Polar expedition. Six days travel and 46 miles from his first food cache on the return journey he ran out of food. Forced to call for help, he described it as the most difficult decision of his life - "hypothermia gives you no choice." (Saunders, B. 2014 TED talk).

Explorers have long understood the need for warmth, and suitable food on expeditions. Fancy new fabrics and energy bars make it simpler and easier but these are seldom constraints. The science of the body's reaction to severe exercise, nutrient balance, hypothermia, dehydration, hypoxia, and sleep deprivation are relatively new.

Severe Exercise.

There is little need for man-hauling these days with modern machines capable of reliable operation in the harsh environment. Explorers can move about using helicopters, snow mobiles, and larger tracked vehicles. Man-hauling is still practiced by adventurers and explorers wishing to pit themselves against the environment and retrace the famous routes of the early heroic age explorers. Modern man-hauling is no less demanding than it was 100 years ago - overland travel in Antarctica is incredibly demanding, it is severe exercise, despite fancy modern equipment.

Humans are faced with three environmental factors that limit our performance in the Antarctic:

- humans perform much better in warn environments than cold due to our African ancestry,
- man-hauling is extremely physical, in an extremely cold environment which requires more energy than can be carried or absorbed to compensate,
- away from the coast, the Antarctic plateau is at an effective altitude of 2800m with the associated problems of hypoxia, and low temperatures.

Explorers and adventurers attempt to carry just the right amount of food to meet their requirements along with a suitable safety margin. Scott worked on the principle that a man should be provided with sufficient food to keep his strength and not an ounce more. Unfortunately his safety margins were too slim and along with shortages at his depots, this caused him significant problems on his return journey. Scott had spent considerable time developing his standard rations providing 4,200 Kcal per day, and summit rations providing 4,600 Kcal per day. See Fig. 2. His daily activities required a greater energy intake and the resulting deficit caused weight loss which is acceptable on short term expeditions, but not on long journeys where the margin for error is greatly reduced.

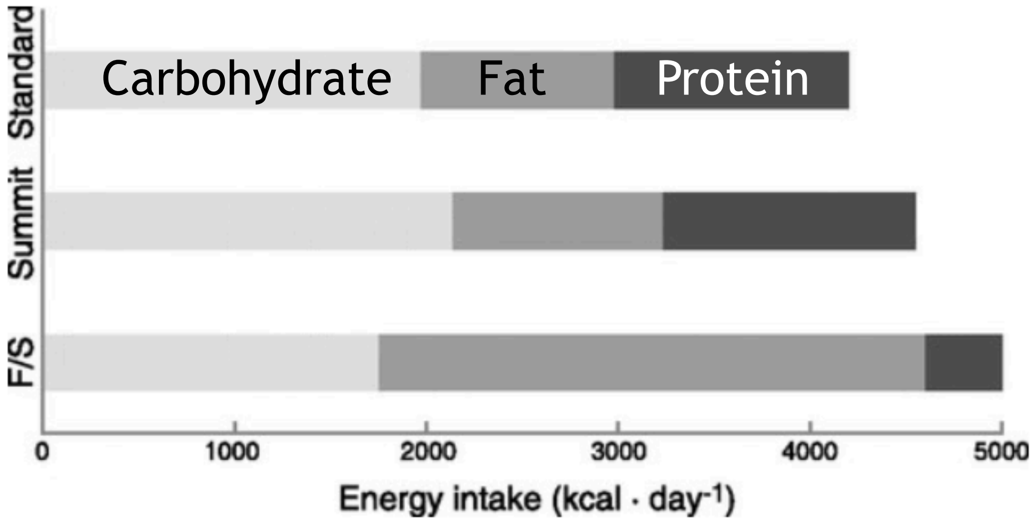

Fig. 2. Scott's Summit and Standard Rations compared with Fiennes and Stroud (F/S). (Lewis G.Halsey and Mike A. Stroud , 2012. P9)

Daily energy requirements are similar between man-haulers and athletes competing in elite endurance races. See Fig. 3. The daily food requirements for man-hauling exceed the food that can be carried with the risk of starvation if supplies cannot be supplemented through caching or re-supply support teams. Fig. 3 also shows the shorter distances achieved by man-hauling compared with modes of transport in optimum conditions.

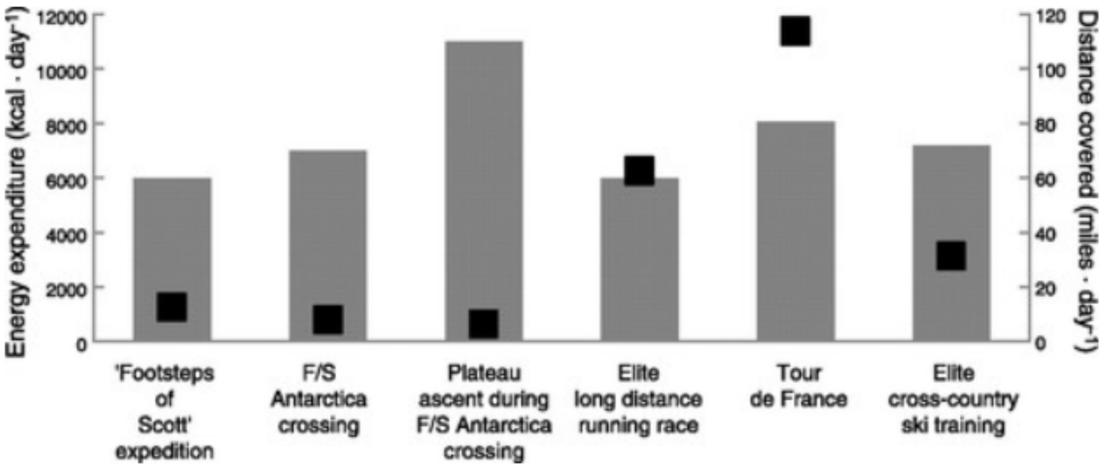

Fig. 3. Daily Energy Expenditure and Distances Covered. (Lewis G.Halsey and Mike A. Stroud, 2012. P6)

In preparation for expeditions requiring severe exercise in extreme cold environments, athletes intentionally put on weight that will be lost during the expedition. The additional weight is used to balance the energy equation when energy out exceeds energy in. The human body cannot absorb enough calories per day to balance the calories used per day in physical exertion and warmth generation. Studies have shown that in recovery athletes can absorb up to 9000 Kcal per day for short periods assisting with weight regain. (Orr, N.W.M. 1964 P87). Further study needs to be undertaken to establish the maximum daily amount that can be consumed over long periods of man-hauling.

Lost weight over the course of an expedition results in two key problems:

- an increased risk of hypothermia due to reduced fat stores and insulation.
- muscle-protein stores decrease reducing strength and reducing daily mileage.

Malnutrition.

With the benefit of modern knowledge on the effects of malnutrition we can prepare a diet of balanced nutrients for use on an expedition. Looking back to the early Antarctic expeditions we see how they struggled with an incomplete understanding of the interactions between the food they selected. In particular, scurvy was a constant problem. They knew it was a problem, and they tried to account for it in their diet (Cook, J. 1776). Around the shores of Antarctica where they could find wild food to supplement their stocks of stored food it was relatively easy to maintain a balanced diet. When travelling inland where all their food had to be carried, the provisioning of food became an important consideration.

Law, P.G. (1956) argues that:

> *The foods used on Antarctic field trips must satisfy different requirements from those used at base. These are as follows: (i) Rations should be standardised for simplicity. (ii) They should be light (no more than two pounds per man per day) and have high calorific value. (iii) They should have a low volume (for example, powders and concentrates). (iv) They should be easy to prepare and not need much cooking. (Fuel is always scarce in the field.) (v) They must be palatable and easily digested. (vi) They must be packed in strong, waterproof and light containers, and must be made up in multiples of man-day quantities which can be easy subdivided. (p. 7)*

The dairies of the men from the heroic age record the time spent during the winter preparing rations for field trips - selecting, sorting and weighting food. Great care was taken making and preparing food bags to contain the rations, all with an understanding of how important this aspect of their preparation was to their survival and success in the field. (Mawson, D. 2013)

The balance of proteins, fats, and carbohydrates carried on these trips does not appear to vary significantly, although when taken over an extended period of time, the cumulative effects of any shortage resulted in most teams marching on starvation rations towards the end of their trips. (Orr, M.W.M. 1964). Fig. 4. shows a comparison of sledging rations used on various expeditions. Quite simply, they were at the extreme end of their range for the weight of food carried. Nothing has changed for modern man-hauling teams. The weight a man can haul is directly proportional to the distance he will travel. Weight saving through dehydrated foods is lost to the increased fuel that must be carried to produce water for rehydration. (Fiennes, R. 2016)

	Winter journey, 1911 (Scott, 1913)	Scott's Summit ration, 1911–12 (Scott, 1913)	Mawson, 1911 (McLean, 1919)	Arctic Air Route, 1930–1 (Lindsay, 1932)	British Grahamland Expedition, 1934–7 (Rymill, 1938)	Falkland Island Dependencies Survey, 1948–50 (Fuchs, 1952)	Falkland Island Dependencies Survey, 1958 (Orr, 1963)	MRC Experimental Box, 1959 (Lewis *et al.* 1963)
Pemmican	12	12	8	8	5·6	5·6	—	—
Biscuit	16	16	12	4	2·7	3·75	4·8	4·0
Butter or margarine	4	2	2	8	5·6	4·8	4·8	5·0
Sugar	—	3	4	4	3·2	3·2	3·1	3·2
Cocoa	—	0·57	1	1	0·8	0·8	0·6	1·5
Tea	—	0·86	0·25	—	—	0·4	0·2	0·25
Chocolate	—	—	2	3	2·4	2·4	0·4	4·0
Milk	—	—	5	2	1·6	1·6	1·6	2·0
Pea flour	—	—	—	2	1·6	0·8	—	—
Oats	—	—	—	3	2·0	2·5	2·4	2·0
Potato powder	—	—	—	—	—	0·8	0·4	1·0
Onion flakes	—	—	—	—	—	0·4	0·4	0·1
Nescafe	—	—	—	—	—	0·2	—	0·25
Marmite	—	—	—	—	—	0·2	0·1	0·1
Bacon	—	—	—	—	—	—	0·8	—
Meat bar	—	—	—	—	—	—	5·0	6·0
Soup powder	—	—	—	—	—	—	1·0	1·0
Fruit bar	—	—	—	—	—	—	1·5	0·75
Curry powder	—	—	—	—	—	—	—	0·25
Cheese	—	—	—	—	—	—	—	2·0
Glucose lemon	—	—	—	—	—	—	—	1·0
Sweets	—	—	—	—	—	—	—	1·0
Pumpernickel	—	—	—	—	—	—	—	0·45
oz/man day	32	34·43	34·43	35	25·5	27·45	27·1	35·85
kcal/man day	5100	5100	5100	5500	4000	4100	3900	5400
Protein (%)	22	28	33	27	19	17	17	14
Fat (%)	42	31	25	34	38	38	37	25
Carbohydrates (%)	36	41	42	39	43	45	46	61

Fig. 4. A comparison of sledging rations, oz/man day. (Orr, N. W. M. P89)

Hypothermia.

Physical activity during man-hauling is very effective in staying warm. The main problem seems to be keeping warm after physical activity in the Antarctic, which has become easier with modern man-made fibres. Clothes are lighter and less susceptible to retaining moisture. Freedom of movement is enhanced thus requiring less energy to move about. Early explorers struggled with heavy, restrictive clothing that was harder to keep dry. Once damp, there are few opportunities to dry clothing, bedding, and footwear in the field. The best strategy is to avoid perspiration by managing the workload to avoid over-exertion. This is practiced by the Eskimos and was a strategy passed on to Amundsen. Above all they taught him not to hurry. “This prevents sweating - the anathema in the cold because it reduces insulation" (Amundsen, R. 2001, Pxxii). Using dogs he was able to balance his teams’ work load and avoid excessive perspiration. Man-haulers by their nature will always struggle with excessive perspiration and susceptibility to hypothermia.

Even during the worst journey in the world, Appsley Cherry-Garrard, while continuously suffering mild hypothermia, kept warm enough to survive in temperatures of ~-60C. Their old-fashioned clothes were capable of keeping them warm, but they were still in constant danger of frost bite when careless to not cover up completely. A big problem was ice accumulation in their clothes and sleeping bags. “Cherry-Garrad’s bag started out weighing eighteen pounds and ended up at forty-five pounds.” (Fiennes, R. 2003, P255).

There is a considerable amount of energy required to stay warm, warm damp clothing, and haul damp camping equipment. All this requires more food to be carried and reduces the range of the man-hauling party.

Effects. Mild hypothermia results in shivering and mental confusion. As severity increases to mild, shivering stops and confusion increases. In severe cases, subjects remove their clothes and there is a risk of cardiac failure.

High Altitude - Hypoxia.

The effect of altitude on human performance is complex.
(Catherine G. Ratzin JacksonBrian J. Sharkey, 2012). An athlete free from illness and disease, and not suffering effects from drugs will generally not be affected by reduced oxygen levels until exceeding an altitude of 3,000m. But if the athlete is moving about quickly in a cold environment then tolerance to hypoxia will be considerably reduced. Reduced physical performance due to oxygen starvation, hypoxia, can start to occur at altitudes over 1500m (Ewing, R.L. 2008). Effects of altitude can also adversely affect brain function, situational awareness, and decision-making. Man-hauling near the coast does not pose any problems, but the average effective altitude of the polar plateau is 2,800m, and there is considerable risk to the effects of hypoxia and reduced performance.

Physical training at high altitude improves performance at high altitude(Bo Berglund, 2012). The most important nutrition factor is iron to assist haemoglobin concentrations. Adaption time from sea level to 2,500m and above indicates a time of about 12 weeks. Athletes can also use Diamox tablets to increase the oxygen-carrying capacity of red blood cells. (Fossett, S. 2006).

Effects. Include confusion, rapid breathing, shortness of breath, and sweating - all which don't help the subjects' performance in the Antarctic.

Sleep Deprivation.

The effects of sleep deprivation become important on longer expeditions where exposure to cold, high altitude, and discomfort make if difficult to get good quality restful sleep.

The psychological effects of acute sleep loss may contribute to decreased tolerance of prolonged heavy exercise (Bruce J. Martin, 1981). Reduced time to exhaustion leaves less time for effective man-hauling and reduces the overall efficiency of the expedition.

Sleep deprivation and periods of wakefulness consume more energy than periods of sleep (Lewis G. Halsey, and Mike A. Stroud, 2112). For man-haulers already on a weight budget this increases the amount and weight of food to be carried.

Effects. Along with daytime fatigue, sleep deprivation negatively affects the subjects mental ability and emotional state. It also compromises decision-making processes.

Dehydration.

Modern athletes are well aware of the need to hydrate to replace water lost due to normal physiological processes of breathing, urination, and perspiration. During periods of extreme exercise in cold, low humidity, and high altitude environments, water loss and water replacement becomes critical to remaining hydrated, yet many athletes fail to identify the symptoms of dehydration and fall into water deficit. In addition, the constant need to take in as much food as possible and not always the appropriate mix of fats, protein, and carbohydrates can create digestive problems causing diorrehea and vomiting with additional water loss.

> *There was no appreciation in Scott's time of the effects that even mild decreases in body water can have, yet rates of water loss are typically high during periods of man-hauling such that even on modern expeditions, short-term dehydration is likely, particularly since cold exposure attenuates thirst (58). The intensity of pulling a sledge triggers sweat production on all but the coldest days and also of course elicits high breathing rates (106, entry 17th December 1911) which, coupled with the dry air of the cold Antarctic environment and the phenomenon of cold diuresis (66), exacerbates water loss (25). This is particularly the case on the polar plateau where altitude leads to even higher respiratory rates and increased diuresis (114, 119). (Lewis G.Halsey and Mike A. Stroud , 2012. P11).*

Taking on water is a continuous activity in the Antarctic not helped by low temperatures that freeze any stored water not kept warmed and insulated from the cold. Keeping water warm through body contact is yet another drain on the body's warmth-generating reserves requiring more food. Obviously there is no shortage of ice to melt for water, and this requires more fuel and adds more weight.

Involuntary Dehydration. Writer describes another source of dehydration:

> *The phenomenon of involuntary dehydration, the delay in full restoration of a body water deficit by drinking, has been described extensively but relatively little is known about its physiological mechanism. It occurs primarily in humans when they are exposed to various stresses including exercise, environmental heat and cold, altitude, water (ice) immersion, dehydration, and perhaps microgravity, singly and in various combinations. The level of involuntary dehydration is approximately proportional to the degree of total stress imposed on the body.*

Leaving out microgravity, an extreme athlete in the Antarctic is in the zone for involuntary dehydration. More study needs to be done on the phenomenon.

Effects. Include fatigue, dizziness, and confusion. Can lead to low blood volume shock - (hypovolemic shock).

Changing the Energy balance.

A study of where the man-hauling teams energy is expended could be used to identify opportunities to extend the range or reduce the weight carried on the sledge.

Factors affecting energy usage:

- total weight of the sledge including food and camping equipment,
- sledge design with changeable runners,
- terrain surface friction - reduced by runner choice,
- ice accumulation due to perspiration,
- ice accumulation due to indoor cooking,
- energy density of daily rations,
- keeping warm when not generating warmth from physical activity.

Conclusions.

Man-hauling requires vast amounts of energy and careful consideration must be given to selecting the appropriate food. Food includes daily rations, but also other inputs including water, oxygen, sleep, and warmth - all necessary for optimum performance in the Antarctic.

The distance achieved by man-hauling teams is constrained by time, the route, and ultimately the speed at which the team can travel. Speed is constrained by weight and the ability to carry enough food-energy to match the amount of energy expended. Even then, the body does not have enough capacity to digest enough food to match the daily exertion.

There was already a great deal of historical knowledge on the calorific value, and mix of carbohydrates, fats, and proteins in an Antarctic man-hauling diet. There is now a greater understanding of the effects of severe exercise, nutrition, hypothermia, hypoxia, sleep deprivation, and dehydration in an Antarctic man-hauling diet. To improve performance these aspects of the daily intake of food need to be considered together. Any mis-match should also be understood and the effects on the well-being of the athlete understood as well.

Factors that affect energy consumption can be optimised to improve performance, but it is hard to imagine that even with all the modern technology at hand today, we will see any great improvement on the achievements of the explorers of the heroic age.

Ultimately, the constraints of time, distance, and speed converge. Scott ran out of time, to complete the remaining distance of the journey, with the resources, both mental and physical, that he had left. Quite simply, they ran out of gas.

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