

Chapter 6

NUTRITION AND MILITARY PERFORMANCE

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INTRODUCTION

It is widely recognized that food has a significant impact on performance. Even in the early part of the 19th century, Baron Dominique Jean Larrey, Inspector General of Napoleon's Military Medical Staff, wrote about the medical conditions and experiences that occurred during Napoleon's disastrous winter campaign against the Russians in 1812:

The ice and deep snow with which the plains of Russia were covered, impeded...calorification in the capillaries and pulmonary organs. The snow and cold water, which the soldiers swallowed for the purpose of allaying their hunger or satisfying their thirst...contributed greatly to the destruction of these individuals by absorbing the small portion of heat remaining in the viscera. The agents produced the death of those particularly who had been deprived of nutriment.¹

Dr Larrey's words provide a dramatic illustration of the significance of food to military performance.

Most military field commanders acknowledge the importance of food for morale purposes, as evidenced by Anthony Kellett's account of rations in *Combat Motivation: The Behavior of Soldiers in Battle*: "...a lack of food (is) the single biggest assault on morale" and "...nothing weakened the will to fight more than did hunger."^{2(p244)} However, other commanders do not consider food to be as important to mission planning as weapons, tactics, vehicle fuel, and other logistical needs.³ In temperate environments, where food and water are plentiful and



Fig. 6-1. Malnourishment contributed to the misery of Civil War soldiers. Photograph shows a Civil War hospital wing. Photograph: Reproduced from the National Archives and Records Administration, Washington, DC. Matthew Brady, photographer.

resupply is reliable, nutrition may diminish in importance, compared with other aspects of combat readiness. Thus, when harsh weather or extreme environmental conditions are superimposed on the physical demands of military operations, nutrition rapidly becomes a prime factor for maintaining performance and preventing disease and injury (Figure 6-1).¹

HISTORICAL ROLE OF THE IMPORTANCE OF FOOD IN MILITARY OPERATIONS

Some military commanders tend to overlook mundane, but important, lessons learned about nutrition from past campaigns. LGCE Pugh, MD, a British physician and high-altitude physiologist, once observed that, "Military people, with due respect, will never listen to physiologists, and, what's more, they will never take lessons from the past. They always have to start everything again from the beginning and find out the hard way. It's always been so and always will be so."^{4(p355)}

Despite Pugh's pessimistic view, the military has spearheaded important advances in our understanding of nutritional disease. Dr Kenneth J Carpenter observed that the early British and Japanese navies were misled by prevailing theories of disease and, as a consequence, were ravaged by diet-related scurvy and pellagra during polar expeditions at sea and bitter land campaigns in Manchuria.⁵ However, lessons learned have been applied, and the record of the US military since World War II in recognizing the role of rations and food technol-

ogy in military medicine is encouraging.⁶ Johnson and Kark⁷ reviewed post-World War II reports on military feeding problems that related to the environment. They concluded that US soldiers were, in large part, able to avoid needless injury in desert, jungle, mountainous, and Arctic theaters because of the superiority of their rations. WB Bean, MD, a nutrition officer during World War II, summarized the role of nutrition in American troops both in garrison and in combat^{8,9}:

In the last year of the war (World War II) we went to the Pacific where we were able to study garrison troops and those in combat ... They had been in serious combat for 4 months of almost daily fighting. The improved C-ration was the only food they had. They were the fittest group we tested anywhere.

Considerable discussion of the proper amount and optimum nutrient composition of military rations continues in today's modern military.¹⁰⁻¹⁶ In retrospect, however, many recommendations concerning the

nutrient composition of military rations have changed little since World War I, as evidenced by a 1919 report by Murlin and Miller:

The amount of protein...sufficient to repair all of the wastes of the body and to supply an adequate reserve is 13% of the total energy intake. It seems a matter of indifference to the muscles whether they receive their energy from carbohydrate or from fat Hard muscular work, therefore, can be done on a diet high in carbohydrate or upon a high fat diet. It is of general experience, however, that muscular work is done with less effort if there is a plentiful supply of carbohydrate.¹⁷

An example of current nutritional practices that are similar to those described by Murlin and Miller is the observed protein intakes in several military surveys, which typically ranged from 13% to 15% (Figure 6-2).¹⁸ Modern military rations have an admirable track record of supporting performance in a variety of moderate environments⁶; however, the situation may change rapidly in theaters of operation characterized by more extreme temperatures and terrain.^{19,20} Rodahl and Issekutz²¹ state the following:

While short-term nutritional deficiencies in men at room temperature appear to have little or no detrimental effect on the capacity to do short term, heavy work, there is a marked reduction in physical work capacity when a nutritional deficiency or nutritional stress is superimposed upon a cold stress.²¹

Based on literature available from field nutritional surveys, the stress from the physical, emotional, and psychological events surrounding peacetime training^{22,23} and combat^{6,8} is usually adequately held at bay by the nutrients provided by conventional military field rations. It is not until stressors such as

- extreme heat,
- cold,
- altitude,
- sleep deprivation, or
- caloric restriction

ENVIRONMENTAL STRESS AND NUTRIENT REQUIREMENTS

The complex interrelationship of environment and human physiology and performance is depicted in Figure 6-3. Energy and fluid deficits arising from the interaction of environment and nutrition can potentially result in both physical and mental performance decrements.^{28,29} Comprehensive reviews of the interaction of environment and nutrition within a military context can be found in workshop publications by the



Fig. 6-2. World War I soldier eating rations in the field. Major John Murlin and his research teams conducted extensive studies on energy intake, weight changes, and macronutrient consumption in the Army in an effort to reduce wasting of food in the military. Photograph: Reproduced from the National Archives and Records Administration, Washington, DC.

are superimposed that performance becomes jeopardized.^{19,20,24} Furthermore, these effects may vary between sexes, warranting different considerations for male and female nutrition in extreme environments. Recent changes in the roles of female soldiers in combat have led to the realization that our knowledge of nutritional requirements for female service members and male-female differences in nutritional requirements may be incomplete.^{25,26} Male soldiers have been the subject of numerous investigations of nutritional requirements and ration developmental efforts, but little research has been directed toward the unique nutritional requirements of female service members.²⁵ Thus, the scope of this review will cover only the effects of environmental extremes on a *known* nutritional challenge facing female soldiers: iron availability.²⁷ Future research is required to determine other potential gender differences in military service members' nutritional needs.

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Cold

After World War II and the Korean War, the influence of cold stress on vitamin requirements was a

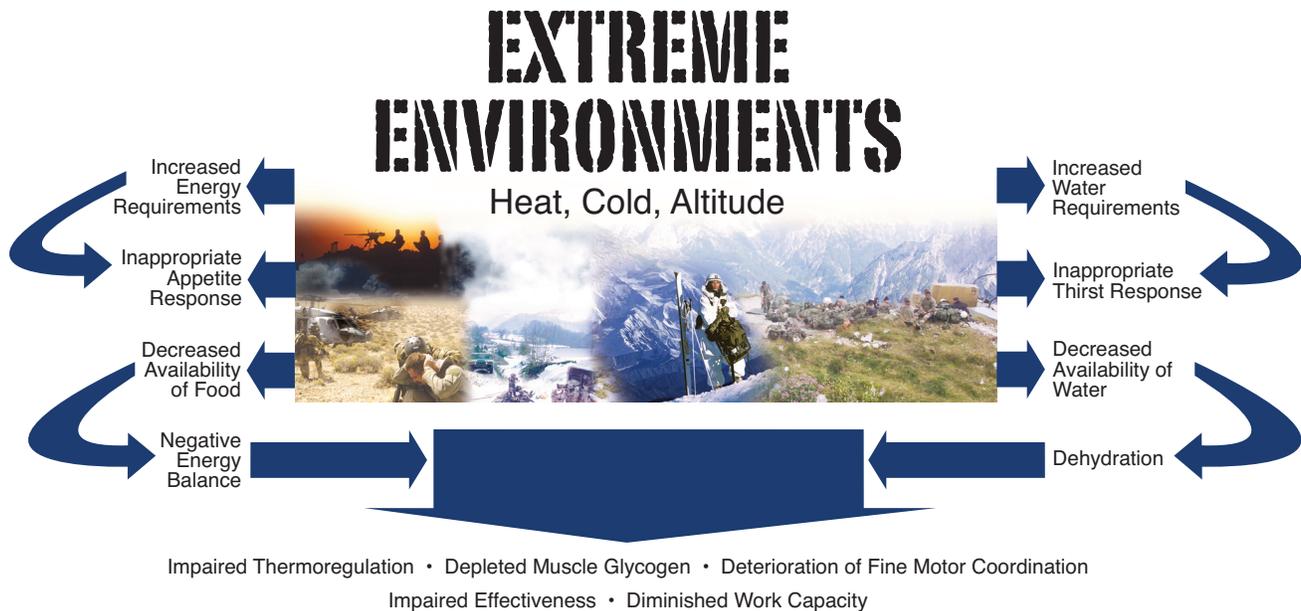


Fig. 6-3. Extreme environments and their influence on physiological function. This generalized cascade of events demonstrates how environment can influence food and water consumption and thus performance.

Illustration: Adapted with permission from Askew EW. Nutrition and performance in hot, cold, and high altitude environments. In: Wolinski I, ed. *Nutrition in Exercise and Sport*. Boca Raton, Fla: CRC Press; 1997.

focus of considerable military and civilian research.³⁰ A clear picture emerged from this research establishing that, although caloric requirements can be elevated, vitamin and mineral requirements are not significantly increased by cold exposure.³¹ Work in the cold can be adequately supported by a variety of combinations of dietary fat, carbohydrate, and protein, although there is some evidence that certain combinations of macronutrients may be more beneficial than others in the ability of soldiers to withstand cold exposure.^{32,33} The compounding effects of intense activity and cold exposure may require more selective nutrient intake. Recent evidence suggests an effective shift from carbohydrate to fat and protein utilization during low-to-moderate intensity shivering in the glycogen-deficient states prevalent in extended field operations.³⁴ However, other experiments revealed that more intense cold-induced shivering increases muscle glycogen utilization, thus increasing the need for dietary intake of carbohydrate.³⁵ The effect of macronutrient source is not as practically significant compared with the consumption of enough total calories to support activity and thermogenesis. The duration and magnitude of cold exposure, as well as the energy requirements of the activities being performed in the cold, should be considered when determining appropriate dietary intake during cold exposure. Total energy expendi-

ture in cold environments has been documented to increase as much as 20% in military personnel³⁶—an effect attributable to the increased physical demand associated with heavy equipment and clothing and traversing difficult terrain (ie, ice and snow). Cold exposure alone may cause increases in metabolic rate, and thus energy requirements if shivering is elicited, because energy demands increase during shivering thermogenesis.³⁷ However, modern cold weather protective clothing effectively limits the degree of cold stress experienced by exposed personnel, and shivering may not be substantial enough to impact overall energy requirements. David Bass,³⁸ an Army thermal physiologist from the US Army Research Institute of Environmental Medicine, explained that: “Man in the cold is not necessarily a cold man!” However, energy deficiency (ie, negative energy balance)—induced by inadequate intake, in concert with elevated stressors such as physical exertion and sleep deprivation—impairs the metabolic (and vasomotor) response to cold exposure, thus increasing the risk for hypothermia.^{39–41} Therefore, increases in total energy intake may be required during prolonged cold weather military operations to offset energy demands of increased work and to prevent cold injury, even when clothing is adequate enough to reduce shivering (Figure 6-4). The increase in total calorie requirements is mainly caused by in-



Fig. 6-4. Data collection for the 1986 USARIEM (US Army Research Institute of Environmental Medicine) field study of MREs (Meals, Ready to Eat), compared with Ration, Cold Weather (RCW) in Alaska. Data collectors are reviewing dietary records and collecting specimens for doubly labeled water energy expenditure measurements from one of the soldiers participating in the study.

creased physical exertion, because it is unlikely that cold exposure itself, in adequately clothed individuals, increases energy requirements more than 10%.^{32,33}

Female soldiers may encounter different challenges in cold environments, compared with their male counterparts. Research on iron requirements and the thermogenic response to cold has identified iron as a key micronutrient sustaining thermoregulation of women exposed to a cold environment.^{39,40} Women

usually consume fewer total food calories than men (proportional to their smaller stature), raising the possibility that female soldiers deployed in cold weather could consume less than the recommended dietary allowance (18 mg), which could impair thermoregulatory response to cold. Whether female soldiers should receive iron-fortified rations is a complex issue that will be discussed later in this chapter.

Although nutrient requirements in the cold are important considerations, they are somewhat secondary to nonnutritional aspects of cold weather operations, such as proper clothing and training. The role of macronutrient mixture becomes more relevant when cold exposure is combined with high altitude, an environment that presents its own unique challenges to maintain proper nutrition in the soldier.²⁰

Altitude

Nutrition surveys conducted with military service members deployed at altitude have shown that early onset of altitude illness reduces appetite and, subsequently, energy and carbohydrate intake (Figure 6-5).^{42,43} This reduced energy intake, combined with the higher energy expenditure observed at altitude (compared with sea level), leads to the tendency for soldiers to be in negative energy balance at altitude.^{36,44,45} Food intake usually increases with time and acclimation, but never meets the level of intake observed at sea level. Weight loss and performance decrements are common under these conditions; thus, altering macronutrient composition may be important in maintaining proper

a



b



Fig. 6-5. Data collection techniques for the 1990 USARIEM (US Army Research Institute of Environmental Medicine) field study of carbohydrate supplementation at altitude. This study was conducted during a military operation at high altitude in Bolivia and demonstrated the value of energy supplementation to offset the anorexic effect that occurs in the first few days at altitude. Recipe specialists completed detailed analyses of food preparation in the kitchen (a) and dieticians (Lieutenant Colonel John Edwards, Army Catering Corps, United Kingdom, shown here) conducted detailed premeal and postmeal estimations of food choice and food waste (b).

nutrition at altitude. For example, although fat is an efficient and well-tolerated energy source during cold weather operations at sea level, it is not as well tolerated at altitude.³² Carbohydrate supplementation of the military diet during field operations at altitudes exceeding 2,200 m is usually an effective method of increasing both carbohydrate and total energy intakes,^{45,46} and may decrease early symptoms of altitude sickness,^{47,48} although not all studies confirm this effect.⁴⁹ Nevertheless, the substitution of carbohydrate for fat and, to a certain degree, for protein can provide metabolic advantages to an individual's oxygen economy while working at altitude (Figure 6-6).⁵⁰ An enhancement of both short-term, high-intensity exercise and long-term, submaximal exercise performance by carbohydrate supplementation at altitude has also been noted.^{42,48} Carbohydrate is a more efficient fuel at altitude than fat because it is already partially oxidized. For example, more oxygen atoms are associated with 1 mol of glucose (molecular weight: 180) than with

an entire mole of palmitate (molecular weight: 256). The metabolism of carbohydrate for energy requires approximately 8% to 10% less inspired oxygen than that required to process a similar amount of calories from fat.

In practical terms, a high carbohydrate diet may reduce the symptoms of acute mountain sickness; enhance both short-term, high-intensity work, as well as long-term, submaximal efforts; and lower the effective operating elevation as much as 300 to 600 M.^{29,50} The most effective carbohydrate supplementation is usually in the form of liquid beverages; soldiers will drink even when they are reluctant to eat.^{45,49} Increasing fluid and carbohydrate intake is beneficial at altitude where fluid losses are increased because of diuresis and humidifying expired air in a usually dry atmosphere (Figure 6-7).⁵¹

Although female soldiers would also benefit from carbohydrate supplementation at altitude, iron may be a more important dietary component to monitor in this

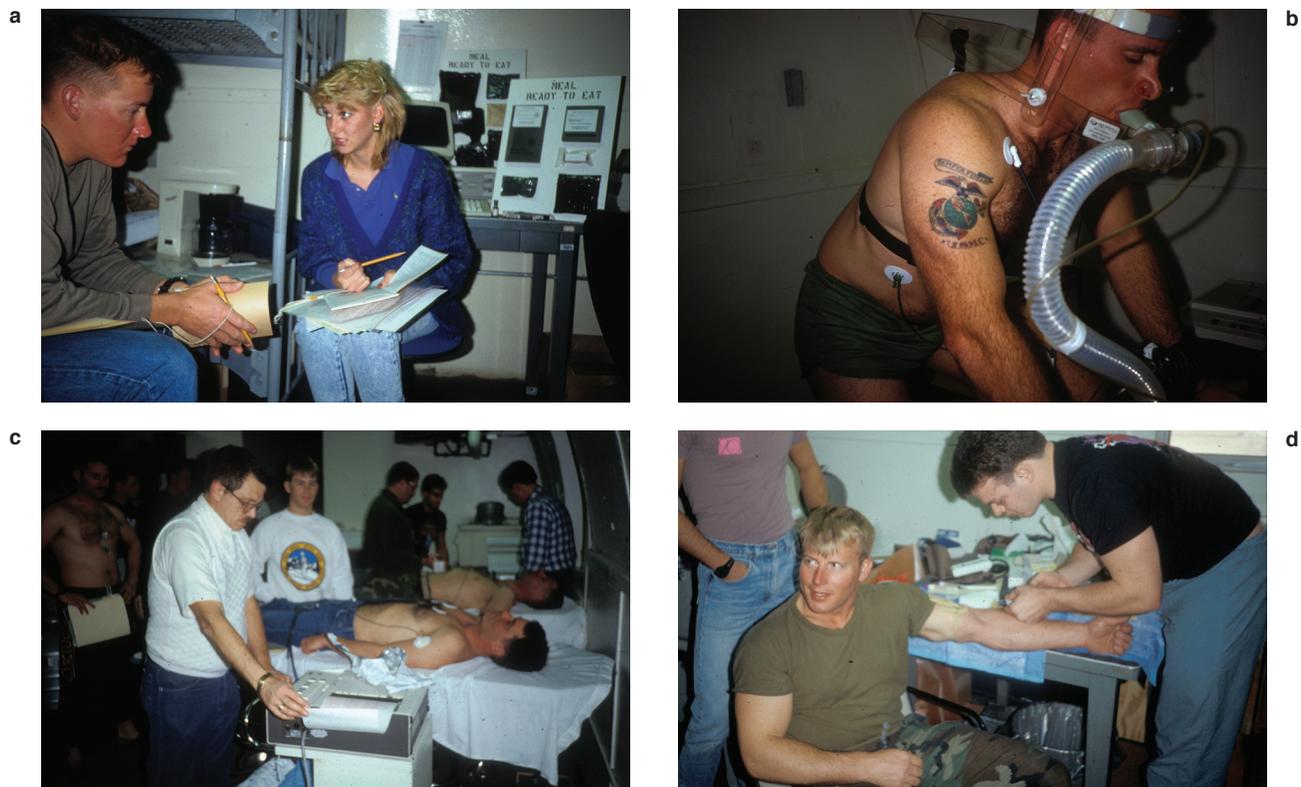
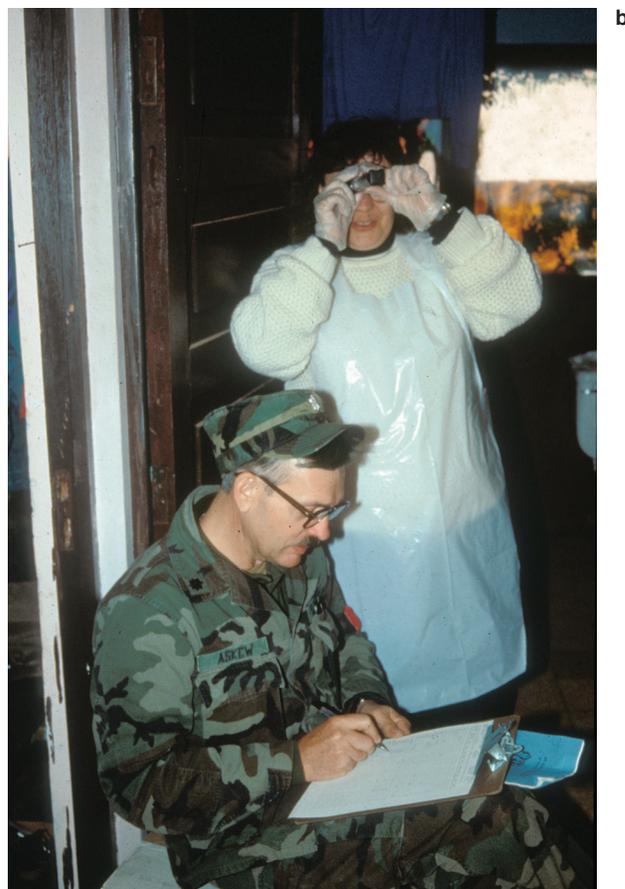


Fig. 6-6. Data collection procedures in the 1988 USARIEM (US Army Research Institute of Environmental Medicine) field study at the Marine Mountain Warfare Training Center, Pickle Meadows, California. This was a winter study involving high intensity work at altitude. Some of the measurements included (a) dietary intakes based on detailed dietary interviews with a dietician; (b) maximal aerobic capacity measurement on a stationary bicycle; (c) cardiovascular function tests, including EKG (shown here being administered by Captain Van Hubbard, National Institute of Diabetes and Digestive and Kidney Diseases [NIDDK]); and (d) biochemical markers were assessed from fasting blood samples drawn from the Marine volunteers.



Fig. 6-7. Hydration status has been a key variable in US-ARIEM (US Army Research Institute of Environmental Medicine) field nutrition studies. Lieutenant Colonel E Wayne Askew organizes 24-hour urine collections with Major Nancy King (a) and records specific gravity measurements made by Elaine Christensen (b) in field laboratories at Fort Riley and at altitude in Bolivia.



population. Studies of women at altitude reveal similar findings to studies of women in the cold in that there is an increased need for dietary iron to mediate adaptive responses to the new environment. Research conducted in the late 1960s identified that female service members deployed to moderate-to-high-altitude environments would require supplemental dietary iron to optimally support their hematopoietic response to hypoxia.⁵² This presents further evidence of the need to closely monitor iron intake in female soldiers deployed to extreme environments (ie, cold or altitude).⁵³⁻⁵⁴

Heat

Not surprising, the most important nutritional considerations for military operations in the heat are fluid and electrolyte replacement, which are discussed in detail in other chapters in this volume. There are, however, a few studies suggesting that macronutrient composition may play a role in optimal performance in the heat. Some⁵⁵ but not all⁵⁶ authors recommend increasing carbohydrate consumption to compensate for increased utilization of muscle glycogen stores and glucose during hyperthermic exercise. The inclusion of carbohydrates in rehydrating fluids can serve a practical purpose by increasing palatability and promoting fluid intake,⁵⁶ irrespective of whether metabolic fuel use is altered in the heat. Total energy expenditure of military personnel does not seem to differ between hot and temperate environments.³⁶ Thus, from a practical standpoint, the total amount of calories consumed in the diet does not need to be adjusted in hot climates.

Stress of Military Training, Oxidative Stress, and Immune Function

As our understanding of the relationship between oxidative stress and chronic disease becomes clearer, a stronger impetus for reinvestigating the optimum level of antioxidant vitamins and minerals in the military diet may emerge. Immune function can be compromised in states of high oxidative stress, such as prolonged physical activity combined with caloric restriction and sleep deprivation.⁵⁷ Studies of US Army Ranger candidates engaged in 8 weeks of training involving high levels of physical exertion, sleep deprivation, mental stress, and food restriction revealed impaired immune response in these soldiers.⁵⁸⁻⁶⁰ Work at altitude may be a particular challenge to human antioxidant defense systems caused, in part, by hypoxia, diet, ultraviolet light, and exhaustive physical activity.⁶¹⁻⁶⁴ Other data have demonstrated elevated markers of oxidative stress and impaired immune function, such as breath pentane, during certain types of military training (Figure 6-8).⁶³ Thus, a natural question remains as to whether administering antioxidant supplements might mitigate these responses. A 2006 review article by Gleeson⁶⁵—reporting

the effects of antioxidant supplementation on immune function—found that, whereas it is likely that vitamin and mineral supplements would improve immune function in individuals exhibiting a deficiency of these factors, it remains to be determined whether administration of an antioxidant supplement would help reduce associated oxidative stress and subsequently bolster the immune response in otherwise healthy individuals. Endurance exercise alone is thought to upregulate inherent antioxidant production, although prolonged endurance activity may result in higher concentrations of reactive oxygen species than can be handled by this training response. Therefore, low-level supplementation of antioxidant vitamins (eg, A, E, C, and beta-carotene) may be warranted in individuals participating in prolonged intense training.

In addition to considering the total energy intake, dietary macronutrient composition could also affect immune function.^{59,60} For example, even moderate dietary protein deficiency has been shown to impair immune function,⁶⁵ and carbohydrate supplementation during prolonged strenuous exercise attenuates markers of elevated immune response. However, it does not appear that carbohydrate supplementation alleviates the effects of intermittent strenuous activity on immune function, as seen in military field operations.⁶⁵

Finally, whereas consideration of antioxidant supplementation in extreme immunodepressive conditions may warrant further consideration, the dangers of oversupplementing with antioxidant nutrients (at high levels that could potentially impair immune function) must also be carefully considered. As an example, iron deficiency is associated with impaired immune function, and, as described previously, female soldiers may be at greater risk for iron deficiency.²⁶ Although increasing the iron content in military rations is one possible solution to this problem, the interaction of excess dietary iron and reactive oxygen species produced during exercise and certain types of environmental exposure suggests that caution may be warranted.⁶⁶ For instance, if 18 mg of dietary iron intake was contained in a typical female caloric intake of 2,000 kcal/d, then a male or female service member ingesting 4,000 kcal/d would receive twice as much or approximately 36 mg of iron/d. Ferrous iron is a cofactor in the propagation of certain harmful free radicals, and excess dietary iron may be undesirable under conditions of increased oxidative stress.^{67,68}

Sports Nutrition and Military Nutrition: Similarities and Differences

Military performance shares much in common with athletic performance.^{69,70} Optimal nutrition to sustain and enhance physical and mental performance for athletic

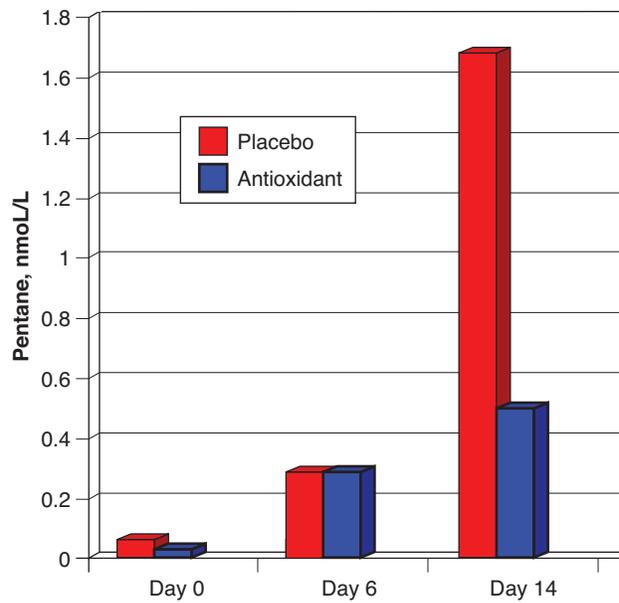


Fig. 6-8. Breath pentane sampled at several time periods during field training at moderate altitude. Breath pentane sampled at the start (Day 0), in the middle (Day 6), and at the end (Day 14) of 14 days of US Marine cold weather field training (elevation 7,000–9,000 feet). The Marines ate military field rations during the training period. The antioxidant supplement consisted of vitamins A, E, and C plus selenium and zinc. Pentane is a hydrocarbon given off following the peroxidation of omega-6 fatty acids in response to free radical damage (oxidative stress).

Illustration: Adapted with permission from Chao W-H, Askew EW, Roberts DE, Wood SM, Perkins JB. Oxidative stress in humans during work at moderate altitude. *J Nutr.* 1999;129:2009–2012.

competition will also have application to military training and combat operations. However, there are some significant differences. During military operations, it is impossible to predict exactly when an intense work period will begin and how long it will have to be sustained. This inherent uncertainty tends to make a classical sports nutrition approach to military feeding and diet planning less useful. The enhancement (or at least the sustainment) of performance of military tasks is best accomplished by providing a basic ration or feeding system that

- maintains body weight,
- provides adequate nutrients for the prevention of nutrient deficiencies,
- provides adequate protein, and
- maximizes carbohydrate intake.^{10,11,40}

Careful attention to these factors ensures that soldiers enter combat with high levels of muscle glycogen (a significant factor in short-term, high-intensity

performance) and protects them from vitamin and mineral shortages that might arise from sporadic ration consumption during combat. Exhibit 6-1 lists a variety of military rations reflecting specific purposes of each ration, and also the improvements in ration development over time.

Role of Vitamins in Physical Performance

Friedl and Hoyt⁷⁰ and van der Beek and colleagues⁷¹⁻⁷⁴ have studied the impact of varying severities of vitamin restriction on physical performance. Dietary vitamin deficiencies produced progressive physical performance impairments. At 60% of recommended daily allowance, restricted intakes of thiamin, riboflavin, pyridoxal phosphate, and ascorbate did not result in a significant performance decrement (maximum workload) after 10 weeks at this level of restriction (Figure 6-9). This can be contrasted with the more immediate effect of acute^{75,76} and long-term chronic⁷⁷ dietary carbohydrate restriction on physical performance (Figures 6-10 and 6-11). Physical performance is much more sensitive to the amount of carbohydrate in the diet in the short term (days) than it is to the vitamin, protein, or fat content.⁶⁹

Role of Carbohydrates in Aerobic Endurance Performance

Both the length of time provided for dietary adaptation to carbohydrate restriction and the amount of carbohydrate in the diet can influence the level of aerobic endurance performance. Figure 6-4 illustrates that aerobic endurance performance can be reduced by 40% after only 4 days on a calorie-adequate, but low carbohydrate diet⁷⁵ (10% kcal). For 2 weeks, a similar calorie-adequate, low carbohydrate diet (5% kcal) also reduced performance, but only by approximately 15%, presumably because of tissue-level adaptations to the shift in energy sources⁷⁶ (Figure 6-11). Furthermore, a reduction in dietary carbohydrate from 83% kcal to 57% kcal had only a small (5%) reduction in performance under similar exercise conditions.⁷⁶ The short-term effects of carbohydrate deprivation may be more relevant to military operations, in which case the observed adaptive response in the 14-day study may not apply, and soldiers may find that endurance performance is decreased when carbohydrate intake is reduced. The effect of any reduction in dietary carbohydrate intake depends on both the period of time over which it is reduced and its absolute level in the diet. Although the studies previously described were not conducted on soldiers, other studies using military test subjects and work performance tests of similar

intensity to military tasks or actual military field maneuvers⁷⁷ have shown that reduced carbohydrate intake has the potential to negatively influence muscle glycogen levels and endurance.⁷⁸

There is abundant evidence in the sports medicine literature to permit extrapolation to military physical performance and to conclude that certain types of military performance may also be impaired by an acute shortage of carbohydrate in the diet. Inadequate carbohydrate in the diet—coupled with successive days of intense, prolonged exercise (sustained operations)—may result in a gradual reduction of glycogen stores, deterioration of performance, and perception of fatigue/work intensity.⁷⁹ The effect of muscle glycogen depletion on perception of exertion is shown in Figure 6-12. As a result of dietary carbohydrate deficiencies, certain military tasks, such as load-bearing work, may be perceived by soldiers to be more difficult.⁸⁰ Carbohydrates may be effective in extending or enhancing military performance when taken before, during, and after moderate- to high-intensity aerobic exercise.⁸¹ Thus, they may be helpful to soldiers as a preload before going into the field, as well as during field training, to sustain performance; carbohydrates may also be helpful to soldiers during postfield operations to speed recovery of local muscle and overall fatigue. This would require a consumption of approximately 500 to 550 g of carbohydrate daily (for male soldiers).⁸² A review of 18 field studies of typical dietary carbohydrate intakes of male soldiers in temperate, hot, and cold environments fed a variety of rations revealed intakes ranging from 244 to 467 g per day.⁸³ Both the mean and median intakes in these 18 studies were 350 g of carbohydrate per day (Figure 6-13). It is apparent that a typical daily 350 g carbohydrate intake, under the best conditions (training, not combat), is considerably less than the 500 to 550 g range recommended for optimal glycogen repletion and physical performance.^{81,82} Total caloric intake by soldiers during military field operations is often less than that required to maintain energy balance (Exhibit 6-2).⁸³ Soldiers do not selectively consume low carbohydrate diets during field training operations; however, total carbohydrate intake is often low simply because total energy intake is low. Often, the rations are “field-stripped,” meaning that soldiers select from the complete ration whatever items can be eaten on the move—regardless of nutrient content—thus leaving the remaining food. Stripping rations may also make the food less bulky to carry and may reflect individual biases regarding food nutritional value, quality, or taste. Inadequate food consumption in the field has been ascribed to the following:

EXHIBIT 6-1

A BRIEF HISTORY OF RATIONS

Historically, ration development was dependent on what was available and what could be transported without spoiling. Under such constraints, the rations were designed around stable foods that could be stored for long periods without spoiling and that could physically withstand the elements of war and field training (Exhibit Figure E1-1). Although some effort was made to provide fresh food to soldiers during those years, the logistics of providing large quantities of fresh meat or vegetables in a war zone were challenging, and such efforts were rarely successful. Thus, in addition to adverse climatic and battlefield conditions, many soldiers were malnourished and suffered illness as a result.

Improvements in food preparation and packaging technology, as well as increased availability of prepackaged foods, changed the focus of ration development. Current ration research considers the macronutrient and micronutrient composition of the foods for each ration under varying conditions. Supplements, or completely separate rations, are available for cold weather operations, altitude, and extended field exercises requiring a high level of sustained physical intensity. Even though the operational environments differ significantly, the requests for ration characteristics are the same: small, lightweight, high calories, and most of all acceptable—if not appealing—to the soldier who has to consume the ration. This has been a focus of the Department of Defense Combat Feeding Directorate at the US Army Natick Soldier Research, Development, & Engineering Center. The taste, texture, and appearance of a ration needed to be taken into consideration as much as the nutrient content. Dr Ancel Keys made the observation that, “A ration that will not be eaten is worse than useless.”⁽¹⁾ Ironically, the K ration, named after Keys, is now a classic example of nutritionally balanced to the point of impalatability.



Fig. E1-1. Field Ration, individual—the K Ration of World War II.
Photograph: Reproduced from the National Archives and Records Administration, Washington, DC.

Ration	Description	Function
Civil War—Marching Ration	Salt pork or fresh meat, hard bread (“hardtack”), sugar, coffee, salt	Field Ration (individual)
Civil War—Camp Ration	Pork/bacon, soft bread, beans, coffee or tea, sugar, salt, pepper, potatoes, vegetables, dried fruits, soap	Garrison Ration (Group Ration)
World War I—Reserve Ration and Trench Ration	Similar to Civil War Marching Ration: canned meat instead of salt pork	Reserve Ration = individual Trench Ration = Group Ration (25 soldiers)
World War II: A Ration	Fresh/frozen meat, fresh dairy, fresh fruits and vegetables, perishables require preparation	Field Kitchen Ration
World War II: B Ration	Canned, dried, dehydrated, nonperishables require preparation	Field Kitchen Ration (up to 100 soldiers, could also be broken up into 10-in-1 ration for small group feeding)
World War II: C Ration	Bread or crackers, spread, meat or protein-based entree, dessert packaged in cans, coffee, sugar, gum, cigarettes and matches	Combat Ration (individual)
World War II: D Ration	Chocolate bars, highest caloric value ration, 3 × 4 ounce bars—highly palatable, useful in all climates, no preparation required	Survival Ration

(Exhibit 6-1 continues)

Exhibit 6-1 *continued*

World War II: K Ration	Highest nutritional value, lightweight, low palatability	Field Ration: individual
Vietnam: Long-Range Patrol	Freeze-dried entrees—require water for rehydration; lightweight, high caloric value	Field Ration: Special Forces restricted use—not nutritionally adequate for extended time periods
MRE	Complete meal, freeze-dehydrated	Field Ration: individual; replaced C Ration
T Ration	MRE in steam-table tray	Group feeding ration (18 soldiers)
Specialty MREs:		
Mountain	Lightweight, food could be prepared at higher altitude (or come precooked), high calories, more “roughage” to assuage hunger	Field Ration: altitude
Arctic Supplement	Additional 900-calorie packet to be used in combination with MRE; contains “warming foods,” such as soups, hot beverages, snacks, and styrofoam containers and cups	Field Ration: cold weather
Cold Weather Meal	High-calorie, extra drink mixes to promote water consumption, packaged in white camouflage	Field Ration: extreme cold weather
Carbohydrate Supplement (CarboPack)	Eat-on-the-move snacks to supplement MREs, 380 calories, 75 g carbohydrates	Field Ration: prolonged, intense physical activity

MRE: meal, ready-to-eat

Note: Many other specialty rations and supplements have now been created, for example, Humanitarian Daily Ration, Kosher Hotel Ration, Survival Food Packets, and the First Strike Ration.⁽²⁾

Data sources: (1) Keys A. *Quartermaster Review*. 1941;XXI(2, Sept/Oct):26–27. (2) Department of Defense. *Operational Rations of the Department of Defense*. 8th ed. Natick, Mass: US Army Natick Soldier RD&E Center/DoD Combat Feeding Directorate; May 2010. Natick PAM 30-25. OPSEC 08-481.

- poor ration palatability,
- menu boredom,
- inadequate time to eat or prepare meals,
- anxiety, and
- intentional dieting to lose weight.¹¹

Whatever the cause, this “voluntary anorexia” of soldiers in the field results in reduced total energy and carbohydrate intake. The lack of energy (calories) itself is not as significant a concern in the short run as is the lack of carbohydrate.⁸⁴ The levels of carbohydrate consumed by soldiers is frequently within the range of carbohydrate intake observed in controlled laboratory studies, resulting in reduced muscle glycogen concentrations and reduced levels of submaximal aerobic performance.^{79,81,82}

The impact of dietary carbohydrate content on military performance is difficult to study under operational conditions because of manifold uncontrolled variables encountered in combat conditions, real or simulated. Thus, definitive field studies dem-

onstrating a positive effect of dietary carbohydrate supplements on military performance are lacking.⁸⁵ However, when field conditions can be simulated under well-controlled laboratory settings, results suggest that performance is improved after carbohydrate supplementation. For example, 18 physically fit US Army Special Operation Forces soldiers completed a study designed to test the concept that soldiers would benefit from carbohydrate supplementation during field operations (Figure 6-14).⁸⁶ These military test subjects were fed a controlled diet that simulated typical carbohydrate and protein intakes (327 g carbohydrate/d, 201 g fat/d, and 118 g protein/d, supplying a total of 3,657 kcal/d) during field operations. The soldiers exercised daily (11 days total) under conditions designed to simulate field energy expenditure patterns (intermittent, as well as sustained activity patterns of varying intensity levels). In addition to the standard diet, each test subject received one of three beverage supplements during the field-simulated diet and exercise program:

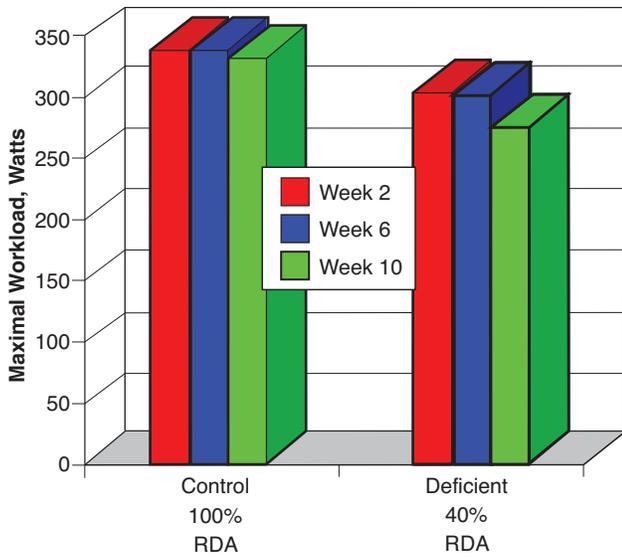


Fig. 6-9. Effect of a restricted vitamin intake (60% RDA) on functional performance in humans. This illustration shows 10 weeks' consumption of either 100% or 40% of the recommended daily allowance for thiamine, riboflavin, pyridoxal, and ascorbate on functional performance (cycle ergometer work) in humans. Note that, even after 10 weeks at 60% vitamin restriction, performance was only decreased approximately 17%.

RDA: Recommended Dietary Allowance

Illustration: Adapted with permission from van der Beek EJ. *Marginal Deficiencies of Thiamin, Riboflavin, Vitamin B-6 and Vitamin C: Prevalence and Functional Consequences in Man.* Amsterdam, The Netherlands: TNO Toxicology and Nutrition Institute; 1992.

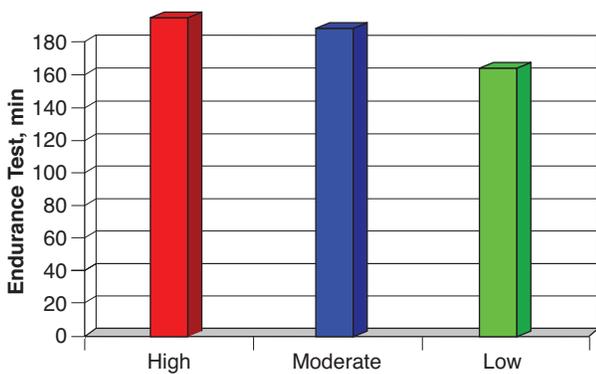


Fig. 6-11. Effect of several levels of long-term (14 days) carbohydrate intake on the performance of intermittent cycle ergometer work. Diets contained high (83%), moderate (56%), or low (24%) amounts of their energy from carbohydrate.

Illustration: Adapted with permission from data reported in Pruett EDR. Glucose and insulin during prolonged work stress in men living on different diets. *J Appl Physiol.* 1970;28:199-208.

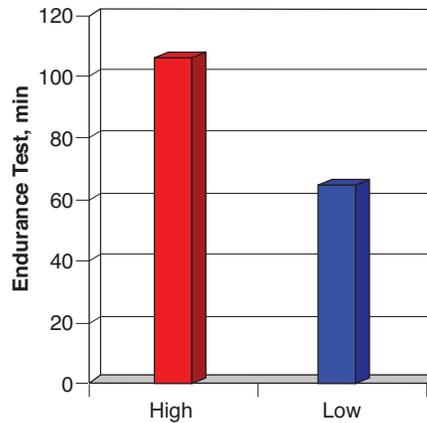


Fig. 6-10. Effect of short-term carbohydrate intakes on the performance of intermittent work. Diets were consumed for 4 days before cycle ergometer work at 70% maximal aerobic capacity. The high carbohydrate diet contained 77% of its calories from carbohydrate, whereas the low carbohydrate diet contained only 10% of its calories from carbohydrate. Illustration: Adapted with permission from data reported in Galbo H, Holst JJ, Christensen NT. The effect of different diets and insulin on hormonal response to prolonged exercise. *Acta Physiol Scand.* 1979;107:19-32.

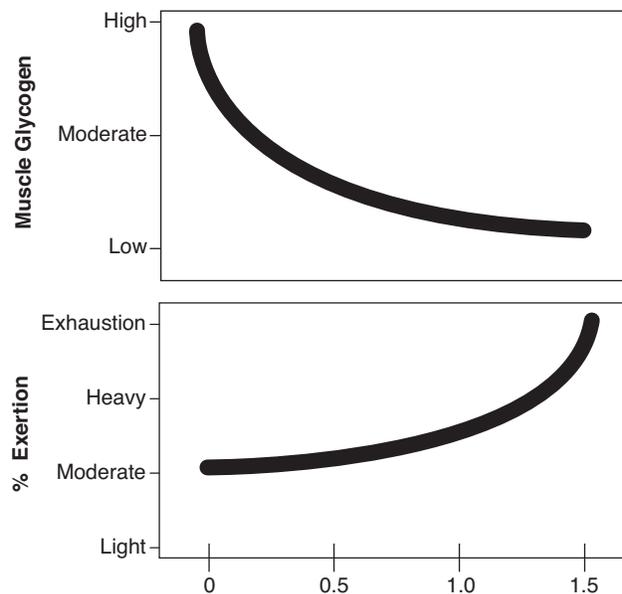


Fig. 6-12. Muscle glycogen depletion and perceived exertion during strenuous training. Note that exhaustion approaches as glycogen levels decrease.

Illustration: Adapted with permission from Sherman WM, Costill DL. The marathon: dietary manipulation to optimize performance. *Am J Sports Med.* 1984;12:44-51.

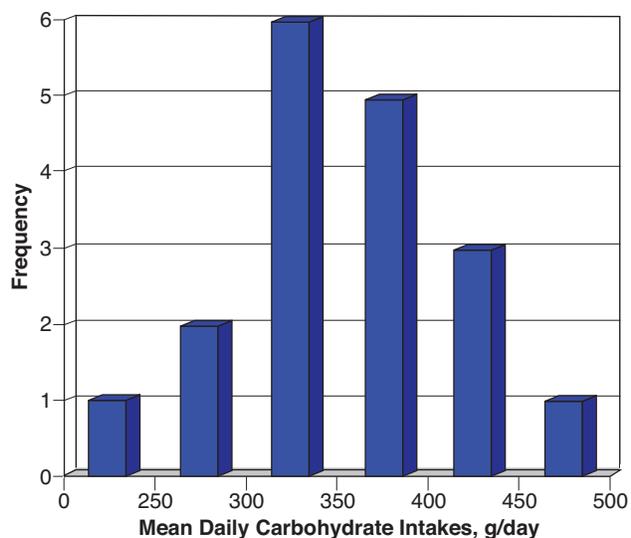


Fig. 6-13. Typical carbohydrate intakes during military field training exercises. Note that more than half the time, dietary intake was less than 400 g of carbohydrate per day. This is not an adequate amount of carbohydrate to replace glycogen used daily in vigorous work (eg, military training). Illustration: Reproduced with permission from Baker-Fulco CJ. Overview of dietary intakes during military exercises. In: Marriott BM, ed. *Not Eating Enough—Overcoming Underconsumption of Military Operational Rations*. Washington, DC: National Academy Press; 1995: 253–283.

1. placebo,
2. carbohydrate (180 g) once a day immediately after exercise, or
3. carbohydrate (180 g) divided into several doses taken after the morning exercise session and at intervals during the afternoon exercise session.

The drop in respiratory exchange ratio that occurred over the 11-day study is illustrated in Figure 6-15. This drop in respiratory exchange ratio was expected and indicated that the soldiers were experiencing a carbohydrate shortage in response to the diet-exercise field simulation and also were experiencing a switch to a fat-predominant metabolism. The provision of supplemental carbohydrate permitted a higher level of physical performance or aerobic power to be obtained. Run times to exhaustion were increased approximately 6%, with the single carbohydrate feeding and 17% with the divided dose (Figure 6-16). The ingestion pattern of the carbohydrate supplement appeared to influence performance, indicating that a supply of easily consumed carbohydrate supplement or food item ingested before, during, and after military field activities would be an effective method

to sustain or boost soldier physical performance. A recent review by Montain and Young⁴⁰ suggests that liquid carbohydrate consumption may be a practical solution to the reduced food intake in the field, because it can be consumed during activity.

How Critical Is Energy Provision?

The previous discussion concerning energy and carbohydrate intakes does not necessarily mean that soldier performance across a broad spectrum of military tasks will be severely degraded by suboptimal energy and carbohydrate intakes. Intense training and associated large energy deficits (3,580–4,540 kcal/d) over 54 hours did not affect energy expenditure or physical activity levels in male and female Marines.⁸⁷ A review of the effect of energy restriction on military work performance has indicated that soldiers can maintain relatively normal work capacities for short periods of food restriction (<10 days).⁸⁴ The Minnesota starvation studies conducted during World War II demonstrated that energy deficits resulting in less than 10% of body weight loss did not impair physical performance; however, underconsumption of calories for longer periods of time producing continued body weight loss did produce significant deficits in physical performance.⁸⁸ More recent studies of food restriction in military scenarios have revealed that restricted energy and dietary carbohydrate content over a 30-day time period supported a light-to-moderate activity level without evidence of greatly impaired physical performance capabilities.⁸⁹ Longer periods of caloric restriction (8 weeks), however, coupled with higher levels of energy expenditure (US Army Ranger training), have been associated with significantly reduced physical performance capacity.⁶² Friedl⁸⁴ has reviewed the influence of reduction in body weight caused by reduced food intake on muscle strength and aerobic capacity. It is difficult to derive a closely predictable relationship between energy deficit and performance because of the differing experimental conditions and performance measures used in various research studies. Grip strength, as a performance measure, seems to be well preserved in military test subjects until nutritional status is severely compromised, whereas other measures—eg, maximal lift, maximal jump height, isometric leg extension, and maximal oxygen uptake—seem to be more sensitive predictors of impaired performance.⁸⁴ Using change in body weight as an indirect indicator of energy deficit, and estimators of muscle strength and maximal aerobic capacity as the dependent variables, generalized relationships between energy deficit and performance

EXHIBIT 6-2

SEX DIFFERENCES IN ENERGY REQUIREMENTS

Energy requirements in military operational and training environments vary enormously. One of the most important variables in estimating these requirements is body mass, because of the amount of metabolically active tissue, as well as the mass that has to be moved through space in any human activity. Body size largely explains the sex differences in energy requirements, although sex steroid hormones also affect energy metabolism at the macronutrient level.

This has been elucidated by a large series of studies using the doubly labeled stable isotope water technique by Reed Hoyt and his colleagues at the US Army Research Institute of Environmental Medicine (USARIEM), in close collaboration with James DeLany and the energy metabolism laboratory at the Pennington Biomedical Research Center.^(1,2) The use of this technique to study energy metabolism in natural conditions outside of a metabolism chamber was promoted in military studies by Colonel E Wayne Askew, with assistance from Rear Admiral Van Hubbard at the National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK).

Energy requirements are similar for men and women when this is calculated on the basis of body mass. This is highlighted in studies with men and women engaged in the same activity, whether relatively low demand in routine duties or in extraordinarily high demand activities in stressful high-risk training and firefighting (Exhibit Table E2-1). Studies of 1 week of Norwegian Ranger training with no organized sleep (<1 hour/day) and no food demonstrated that women are more efficient in fat metabolism in a semistarvation setting, an apparent estrogen-related effect.^(3,4) Because of the greater availability of fat stores in most women, compared with normal men, they would also survive longer with limited energy intake.

Health and performance are not impaired if energy intake is sufficient to meet the demands.⁽⁵⁾ This was demonstrated for women exercising intensively and debunked the myth that female soldiers would develop amenorrhea and consequent risks for bone loss and other estrogen-related functions simply from high levels of exercise.⁽⁶⁾

The importance of adequate energy intake was also demonstrated for sustained performance in men, debunking a second myth that humans break down with prolonged continuous exercise. Two Norwegian SEALs were studied during a south-north endurance trek of 3,000 km across Greenland and demonstrated that, with an energy-supplemented diet of nearly 6,000 kcal/day, body energy stores and performance were sustained, unlike Ranger training with high activity and inadequate energy intake.^(7,8)

Data sources: (1) DeLany JP, Schoeller DA, Hoyt RW, Askew EW, Sharp MA. Field use of D2 18O to measure expenditure of soldiers at different energy intakes. *J Appl Physiol.* 1989;67:1922–1929. (2) Delany JP. *Determination of Total Daily Energy Requirements and Activity Patterns of Service Women.* Baton Rouge, La: Louisiana State University and A&M College; October 2001, 39 pp. Final Report DAMD17-96-2-6025. (3) Young VR. *Metabolic Response to Food Restriction in Military-Eligible Women Within a Gender Comparison.* Cambridge, Mass: Massachusetts Institute of Technology; October 1999, 79 pp. Final Report DAMD17-95-2-5014. (4) Hoyt RW, Friedl KE. Field studies of exercise and food deprivation. *Curr Opin Clin Nutr Metab Care.* 2006;9:685–690. (5) Friedl KE. Biomedical research on health and performance of military women: accomplishments of the 1994 Defense Women's Health Research Program (DWHRP). *J Women's Health.* 2005;14:764–802. (6) Loucks AB, Thuma JR. Luteinizing hormone pulsatility is disrupted at a threshold of energy availability in regularly menstruating women. *J Clin Endocrinol Metab.* 2003;88:297–311. (7) Frykman PN, Harman EA, Opstad PK, et al. Effects of a three-month endurance event on physical performance and body composition: the G2 Trans-Greenland Expedition. *Wilderness Environ Med.* 2003;14:240–248. (8) Friedl KE, Moore RJ, Hoyt RW, et al. Endocrine markers of semistarvation in healthy lean men in a multistressor environment. *J Appl Physiol.* 2000;88:1820–1830.

(Exhibit 6-2 continues)

can be characterized as being similar to those shown in Figures 6-17 and 6-18. In general, strength seems to be rather well maintained up to 5% of body weight loss, and aerobic capacity is only reduced when body weight loss exceeds 10%. The interpretation of studies appearing to produce data such as those in Figures 6-17 and 6-18 must be qualified. Maximal aerobic capacity is not a good determinant of overall military

performance. Grip strength, although a useful indicator for severely catabolic or starved individuals, does not seem to be a sensitive indicator of energy deficit in otherwise healthy soldiers. In addition, the relationship between body weight loss and aerobic capacity must be expressed independent of body weight. It should be noted also that motivation can overcome modest physiological decrements, such

Exhibit 6-2 continued

TABLE E2-1

SUMMARY OF ENERGY EXPENDITURE STUDIES USING DOUBLY LABELED WATER MEASUREMENTS AND INVOLVING MEN AND WOMEN IN MILITARILY RELEVANT ENVIRONMENTS⁽¹⁾

Activity	TDEE (SD) (MJ/d)		TDEE/Kg Body Mass (MJ/kg/d)	
	Women	Men	Women	Men
Norwegian Ranger cadet training ⁽²⁾	21.9 (2.0) <i>n</i> = 6	26.6 (2.0) <i>n</i> = 10	0.34	0.35
US Marine recruit crucible exercise ⁽³⁾	19.8 (0.6) <i>n</i> = 20	25.7 (0.8) <i>n</i> = 29	0.34	0.35
Smoke jumpers ^(4,5)	14.8 (3.0) <i>n</i> = 9	20.3 (3.0) <i>n</i> = 7	0.23	0.28
US Marine recruit training ^(6,7)	9.9 (1.6) <i>n</i> = 20	16.9 (4.0) <i>n</i> = 10	0.17	0.23*
US Army mass casualty training ^(6,7)	12.1 (1.0) <i>n</i> = 10	16.4 (3.7) <i>n</i> = 6	0.20	0.19
US Navy sailors at sea ^(6,7)	11.6 (1.8) <i>n</i> = 16	14.4 (3.6) <i>n</i> = 9	0.17	0.18

d: day; MJ: millijoule; SD: standard deviation; TDEE: total daily energy expenditure.

*This study demonstrated significant gender differences when corrected for body weight.

Notes: All TDEE means were significantly different between men and women ($P < 0.05$). US Marine recruit training was similar for men and women, but not conducted in mixed gender teams.

Data sources: (1) Friedl KE, Ness JW. *Upper Limits of Energy Expenditure for Men and Women in Military Operational Settings: Does Female Fat Metabolism Provide a Performance Advantage?* NATO HFM-158 Symposium on "Impacts of Gender Differences on Conducting Operational Activities." Neuilly-sur-Seine Cedex, France: Research and Technological Organization, North Atlantic Treaty Organization; 2008. (2) Hoyt RW, Opstad PK, Haugen AH, et al. Negative energy balance in male and female rangers: effects of 7 days of sustained exercise and food deprivation. *Am J Clin Nutr.* 2006;83:1068–1075. (3) Castellani JW, DeLany JP, O'Brien C, et al. Energy expenditure in men and women during 54 h of exercise and caloric deprivation. *Med Sci Sports Exerc.* 2006;38:894–900. (4) Ruby BC. *Training and Extended Operations in Females: Effects on Reproductive Hormones, Bone Health, Task Specific Performance, and Comparative Energy Utilization.* Missoula, Mt: The University of Montana; October 1999, 60 pp. Final Report DAMD17-96-1-6329. (5) Ruby BC, Shriver TC, Zderic TW, et al. Total energy expenditure during arduous wildfire suppression. *Med Sci Sports Exerc.* 2002;34:1048–1054. (6) Delany JP. *Determination of Total Daily Energy Requirements and Activity Patterns of Service Women.* Baton Rouge, La: Louisiana State University and A&M College; October 2001, 39 pp. Final Report DAMD17-96-2-6025. (7) Tharion WJ, Lieberman HR, Montain SJ, et al. Energy requirements of military personnel. *Appetite.* 2005;44:47–65.

as reduced maximal aerobic capacity. Changes in maximal oxygen consumption, in response to modest caloric restriction, can influence soldier performance to a lesser degree than reductions in muscle strength in response to weight loss. The primary concern of weight loss from inadequate energy intake during military operations appears to be the loss of muscle mass and therefore muscle strength. Significant loss of muscle strength occurs between 5% and 10% of body weight loss (Figure 6-19). Significant declines in aerobic capacity can also occur following weight losses of this magnitude, but the decline in aerobic capacity appears to have relatively little effect on

soldier performance at moderate levels of sustainable workload.⁸⁴

There are, however, factors other than strength and aerobic capacity to consider when evaluating the effects of energy restriction on soldier performance.¹¹ Weight losses of 6% or less over periods of 10 to 45 days generally do not produce significant degradations in cognitive performance. However, habitual or forced reduction in consumption, resulting in greater than 50% loss of energy requirements, may significantly degrade cognitive performance.⁹⁰ Reduced food intake, when coupled with other stressors (eg, high rates of energy expenditure and sleep deprivation), can impair immune function.⁶⁴



Fig. 6-14. Sophisticated laboratory metabolic studies have been conducted with the Army at the Pennington Biomedical Research Center in Baton Rouge, Louisiana. In a 1993 study of interindividual differences in exercise metabolism, a group of Special Force soldiers were housed and tested at the Pennington Center with detailed measurements of metabolic performance during (a) exercise to exhaustion and (b) postexercise. This study revealed more about the value of carbohydrate supplementation during exercise than any major differences in fuel metabolism between individuals.

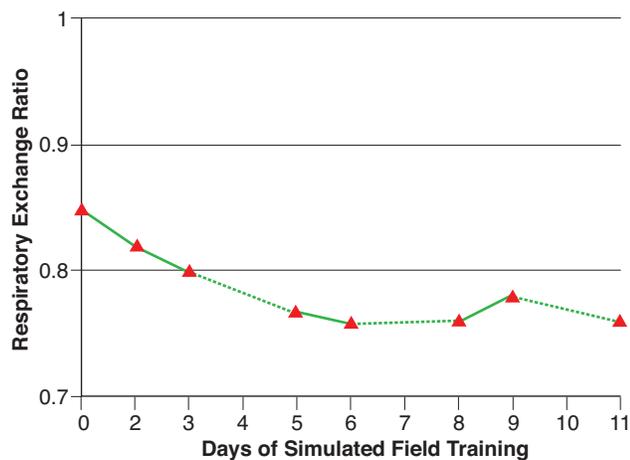


Fig. 6-15. Effect of military field diet on respiratory exchange ratio. This illustration shows the respiratory exchange ratio during exercise over 11 days of suboptimal carbohydrate intakes (300 g/d). Test subjects were US Special Forces soldiers performing daily bouts of treadmill exercise. Illustration: Reproduced with permission from Murphy TC, Hoyt RW, Jones TE, et al. *Performance Enhancing Ration Components Program: Supplemental Carbohydrate Test*. Natick, Mass: US Army Research Institute of Environmental Medicine; 1994. Technical Report T95-2.

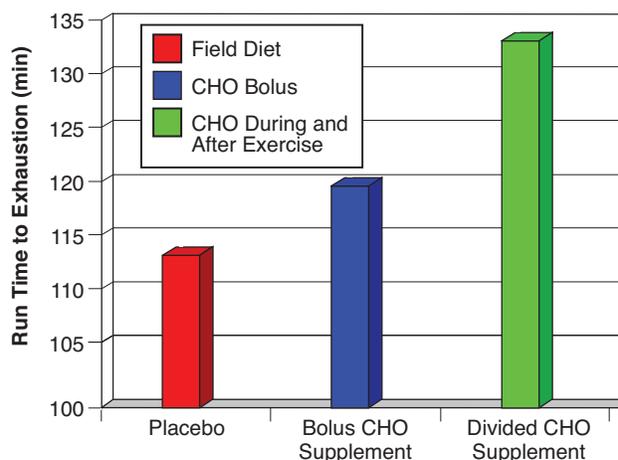


Fig. 6-16. Effect of carbohydrates on performance. This illustration shows the effect of carbohydrate supplementation on treadmill performance by the US Special Forces soldiers following 11 days of training. The test occurred in the afternoon following a 2-hour bout of treadmill running in the morning. Carbohydrate was supplemented either as a placebo (0 carbohydrate), as a bolus at the end of the preceding bout of exercise, or as a divided dose during and after exercise (approximately 180 g carbohydrate supplemented). CHO: carbohydrate. Illustration: Reproduced with permission from Murphy TC, Hoyt RW, Jones TE, et al. *Performance Enhancing Ration Components Program: Supplemental Carbohydrate Test*. Natick, Mass: US Army Research Institute of Environmental Medicine; 1994. Technical Report T95-2.

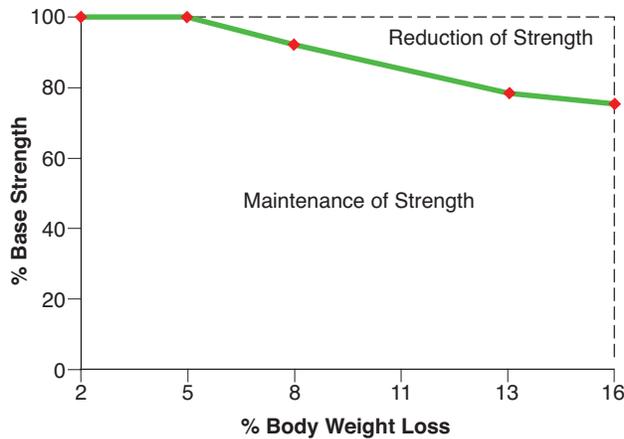


Fig. 6-17. Generalized relationship between body weight loss and maintenance of strength, based on analyses of several military field studies. Strength is well-maintained until body weight loss exceeds 10%.

Illustration: Adapted with permission from Friedl KE. When does energy deficit affect soldier physical performance? In: Marriott BM, ed. *Not Eating Enough—Overcoming Underconsumption of Military Operational Rations*. Washington, DC: National Academy Press; 1995: 267.

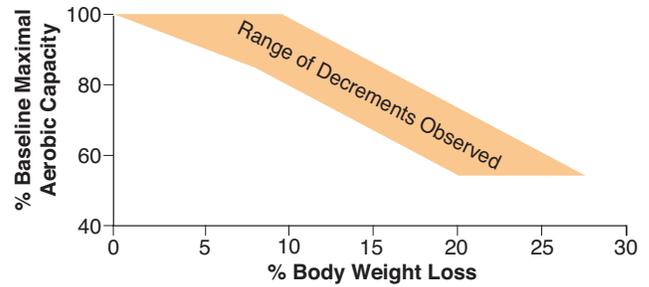


Fig. 6-18. Generalized relationship between body weight loss and maximal aerobic capacity. Note that aerobic capacity begins to drop sharply after 10% weight loss is exceeded. Illustration: Adapted with permission from Friedl KE. When does energy deficit affect soldier physical performance? In: Marriott BM, ed. *Not Eating Enough—Overcoming Underconsumption of Military Operational Rations*. Washington, DC: National Academy Press; 1995: 271.

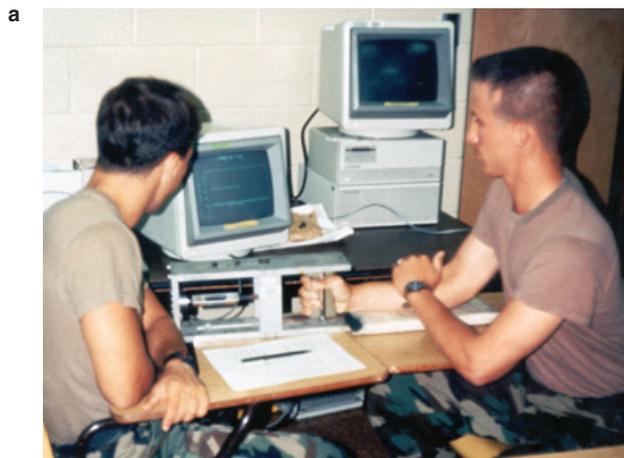


Fig. 6-19. Strength measurements in USARIEM (US Army Research Institute of Environmental Medicine) field studies of Ranger training included (a) specific grip strength performance (testing shown at the beginning of Ranger training) and (b) lifting performance measured in the incremental dynamic lift test (testing shown part way through training). Grip strength performance was well preserved even in the face of large catabolic changes, whereas strength involving larger muscle groups, such as the lift test, demonstrated 20% reduction, reducing mean strength performance of Ranger students to that of the average soldier.

Photographs: Courtesy of Colonel Karl E. Friedl.

SUMMARY

The overriding theme present in discussions of optimal nutrition for cold weather, heat, altitude, or sustained operations is adequate total energy intake. There are reasonable data to support specific alterations in macronutrient composition of diet to enhance performance under the previously described environmental stresses. However, no amount of increased carbohydrate, protein, or fat will negate the effects of an underfed soldier. This is particularly true when negative energy balance is sustained for prolonged periods of time.

The problem of inadequate consumption of dietary energy and carbohydrate can be addressed in both a behavioral and feeding plan context and has been discussed in *Not Eating Enough—Overcoming Underconsumption of Military Operational Rations*.¹¹ The desirability or advisability of supplementing the diet of soldiers

with other nutrients has been similarly addressed in other symposiums on aspects of military nutrition.^{10–16} General agreement exists in these publications that vitamin and mineral intakes furnished by fortified military rations are adequate, even when situationally influenced by short-term reduced food intake. A possible exception to this generality may exist for certain antioxidant nutrients, and for women, iron intake.²⁷ Thus, the most significant nutritional problem facing soldiers in training and combat is underconsumption of rations. This can lead to suboptimal intakes of energy, carbohydrate, and certain antioxidant nutrients. As noted by David D Schnakenberg (Colonel, US Army, Ret), former commander of the US Army Research Institute of Environmental Medicine, “A ration is a ration, even if it is not eaten, but it must be consumed to be nutrition” (DD Schnakenberg, circa 1986).

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