Chapter 7

WATER REQUIREMENTS AND SOLDIER HYDRATION

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INTRODUCTION

The provision of sufficient potable water to sustain soldier hydration is a prerequisite for successful deployment. Adolph et al. and Eichna et al. documented that dehydration can degrade soldier morale, as well as the desire to work (Figure 7-1). Body water deficits as little as 2% body weight can impair physical performance. Water deficits of 5% to 7% of initial body weight are associated with dyspnea, headache, dizziness, and apathy. An extreme example of the threat dehydration poses to troops is shown by the deaths of many Egyptian soldiers who were cut off from needed supplies and who suffered water deficits and heat illness during the 1967 Six-Day War.

During military operations, an individual soldier’s daily water requirements to sustain hydration can range from 2 L/d to an excess of 12 L/d, depending on weather conditions, workload, and physical size. Although 2 L/d is relatively easily achieved both in garrison and during deployment, 12 L/d will require concerted effort and coordination by military logistic support personnel and field commanders to ensure that adequate fluid is available (Figure 7-2). It is the responsibility of medical personnel to educate unit leaders about the importance of hydration and the necessary measures to optimize fluid intake and retention. This chapter discusses the effect of harsh environments on fluid requirements and presents methods to sustain water balance during deployment to environmental extremes.

WATER-ELECTROLYTE BALANCE

The human body is composed mainly of water. It accounts for 50% to 70% of body weight for an adult man and 40% to 60% of body weight for an adult woman. Water is primarily distributed in nonfat tissue and accounts for 72% to 73% of lean body mass. The large, between-individual variation in total body water relative to body weight is primarily a function of body fat (ie, adipose tissue is a major contributor to an increase in body weight without a corresponding increase in body water). The typical male soldier has 47 L of body water, whereas the typical female soldier has 33 L of body water.

On a daily basis, body water is relatively stable, provided adequate fluid is available to offset water lost by sweating, respiration, and urination. Water balance is regulated daily to within ~0.66% of body weight in healthy, active populations. This tight balance is achieved through fluid ingestion associated with eating and drinking, coupled with metabolic water production and physiological systems that regulate fluid loss (eg, renal, cardiovascular, and hormonal systems). Table 7-1 illustrates the sources of water losses and production, as well as the lower estimates of the turnover from these sources. It should be recognized, however, that the values presented can vary markedly. Respiratory water losses, for example, can range from 0.2 L/d in humid air to more than 1.5 L/d during exercise at extremely high altitudes. Cutaneous sweating can increase from 0.5 L/d to more than 10 L/d with prolonged exercise in hot environments. Similarly, diarrhea can greatly increase fecal water losses. For more information, the Institute of Medicine has published dietary reference intakes for water and electrolytes.

Body water levels can vary markedly throughout a day. It is not uncommon for athletes or soldiers to lose 2% to 5% of body weight during physical activity, and make up the short-term water deficit by drinking during rest periods and at meals. This pattern of voluntary dehydration during physical activity—followed by drinking the majority of daily water intake at mealtimes—results in marked fluctuations that are not apparent during day-to-day examinations of total body water measurements.

Body water is distributed in three principal fluid compartments: (1) intracellular, (2) interstitial, and (3) intravascular. Movement within the intracellular and extracellular compartments is determined largely by osmotic forces; therefore, maintenance of total body water is dependent on total solute and distri-
Water Requirements and Soldier Hydration

Fig. 7-2. World War II soldier using a steel helmet to hold water and to bathe. Earlier beliefs that water restriction would improve human tolerance to dehydration were not borne out by the careful studies of Adolph and others in the 1940s. Photograph: Reproduced from the National Archives and Records Administration, Washington, DC, photo no. 208-AA-4NN-24.

TABLE 7-1
ESTIMATES OF MINIMAL DAILY WATER LOSSES AND PRODUCTION*

<table>
<thead>
<tr>
<th>Source</th>
<th>Loss (mL/d)</th>
<th>Production (mL/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory loss</td>
<td>–250 to –350</td>
<td></td>
</tr>
<tr>
<td>Urinary loss</td>
<td>–500 to –1,000</td>
<td></td>
</tr>
<tr>
<td>Fecal loss</td>
<td>–100 to –200</td>
<td></td>
</tr>
<tr>
<td>Insensible loss</td>
<td>–450 to –1,900</td>
<td></td>
</tr>
<tr>
<td>Metabolic production</td>
<td>—</td>
<td>+250 to +350</td>
</tr>
<tr>
<td>Total</td>
<td>–1,300 to –3,450</td>
<td></td>
</tr>
<tr>
<td>Net loss</td>
<td>–1,050 to –3,100</td>
<td></td>
</tr>
</tbody>
</table>


Neither the brain nor liver lost significant water content. Thus, dehydration results in water redistribution largely between the intracellular and extracellular spaces of muscle and skin.

Sweat-induced dehydration decreases plasma volume and increases plasma osmotic pressure in proportion to the level of fluid loss. Plasma volume decreases because it provides the precursor fluid for sweat. Osmolality increases because sweat is ordinarily hypotonic relative to plasma. Sodium and chloride are primarily responsible for elevated plasma osmolality. It is the plasma hyperosmolality that mobilizes fluid from the intracellular space to the extracellular space and enables plasma volume defense when a person is dehydrated.

THIRST AND SATIATION

Several factors stimulate thirst and play a role in satiation. The most studied mechanism is in osmoreceptor cells, which are activated by intracellular dehydration. These cells—located in the preoptic/hypothalamic region of the brain—are sensitive to cell volume reductions induced by either extracellular hypertonicity or isoosmotic water loss (eg, hemorrhage, diuretic administration). Activation of these cells stimulates both thirst and arginine vasopressin (AVP) secretion. Stimulation of AVP secretion increases the desire to drink and facilitates water retention by increasing renal water reabsorption.

Changes in extracellular fluid volume also contribute to thirst and water balance. Evidence indicating
that water volume is independent of osmotic stimuli comes from experiments that have manipulated blood volume or cardiac filling or both. Increased blood volume or central venous pressure (eg, head-out immersion) leads to diuresis, reduced thirst, and voluntary water intake. In contrast, central venous pressure reductions from hemorrhage, diuretics, or lower body negative pressure decrease urine output and increase thirst and drinking. Sensitivity of the response is much lower, however, than the osmotic thirst mechanism and seems to be more effective with intact kidneys, thus suggesting that the renin-angiotensin system contributes to thirst response. Animal experiments have demonstrated that angiotensin II can be a potent dipsogen. Receptors for angiotensin II exist in the preoptic/hypothalamic regions of the brain. Intraventricular infusion of small quantities of angiotensin II stimulate thirst. Pharmacological blockade of angiotensin I-type receptors and angiotensin II receptors reduces the thirst response accompanying food intake, hemorrhage, and water deficit. Whether systemic angiotensin II plays a direct role in stimulating thirst in humans remains unclear. Current evidence suggests that blood-borne angiotensin II binds to receptors within the preoptic/hypothalamic regions, and the transduced signal is integrated with other inputs from systemic arterial blood pressure and volume receptors.

Unpleasant oral sensations also play a role in stimulating voluntary fluid intake. Several studies have demonstrated that 24 hours of fluid abstinence produces a marked increase in the subjective ratings of thirst, mouth dryness, and unpleasant taste. The reversal of these oral sensations is significantly correlated with subsequent water intake. Similarly, induction of graded levels of dehydration by food restriction, fluid restriction, and exercise-heat stress are accompanied by graded increases in the number and magnitude of

### TABLE 7-2

<table>
<thead>
<tr>
<th>Life-Stage Group</th>
<th>Criterion</th>
<th>Adequate Intake‡ (L/d)</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>From Foods</td>
<td>From Beverages</td>
<td>Total Water</td>
</tr>
<tr>
<td>0–6 mos</td>
<td>Average consumption of water from human milk</td>
<td>0.0</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>7–12 mos</td>
<td>Average consumption of water from human milk and complementary foods</td>
<td>0.2</td>
<td>0.6</td>
<td>0.8</td>
</tr>
<tr>
<td>1 yr</td>
<td>Median total water intake from NHANES III</td>
<td>0.4</td>
<td>0.9</td>
<td>1.3</td>
</tr>
<tr>
<td>4–8 yrs</td>
<td>Median total water intake from NHANES III</td>
<td>0.5</td>
<td>1.2</td>
<td>1.7</td>
</tr>
<tr>
<td>9–13 yrs</td>
<td>Median total water intake from NHANES III</td>
<td>0.6</td>
<td>1.8</td>
<td>2.4</td>
</tr>
<tr>
<td>14–18 yrs</td>
<td>Median total water intake from NHANES III</td>
<td>0.7</td>
<td>2.6</td>
<td>3.3</td>
</tr>
<tr>
<td>&gt;19 yrs</td>
<td>Median total water intake from NHANES III</td>
<td>0.7</td>
<td>3.0</td>
<td>3.7</td>
</tr>
<tr>
<td>Pregnancy</td>
<td>Same as median intake for nonpregnant women from NHANES III</td>
<td>0.7</td>
<td>2.3</td>
<td>3.0</td>
</tr>
<tr>
<td>14–50 yrs</td>
<td>Same as median intake for nonlactating women from NHANES III</td>
<td>0.7</td>
<td>3.1</td>
<td>3.8</td>
</tr>
</tbody>
</table>


*No Tolerable Upper Intake Level is established; however, maximal capacity to excrete excess water in individuals with normal kidney function is 0.7 L/h.

Total water represents drinking water, water in other beverages, and water (moisture) from food. (See Table S-1 in Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate for the median percentage if total water intake from beverages [including drinking water] and from foods reported in the NHANES III.)

‡The observed average or experimentally determined intake by a defined population or subgroup that appears to sustain a defined nutritional status, such as growth rate, normal circulating nutrient values, or other functional indicators of health. Adequate intake is used if sufficient scientific evidence is not available to derive an Estimated Average Requirement. Bold numbers = adequate intake is not equivalent to a Recommended Dietary Allowance. (Adequate intake is provided where no Recommended Dietary Allowance has been established.)

unpleasant oral sensations.\textsuperscript{26} Sensations showing a linear trend with dehydration level include the following:

- dry and irritated throat;
- chapped lips;
- feelings of weariness, dizziness, and appetite loss; and
- thinking of drinking.

To examine if these oral sensations contributed to drinking behavior, Phillips and colleagues\textsuperscript{10} obtained blood samples and visual analog scale thirst measurements at hourly intervals and when volunteers drank water during a normal working day. They found that sensations of thirst, mouth dryness, unpleasant mouth taste, and the pleasure of drinking water increased before ad libitum intake, with no concomitant changes in blood tonicity or volume. These results provide evidence that, during free access to water, humans become thirsty and drink before body water deficits accrue, perhaps in response to subtle oropharyngeal cues.\textsuperscript{10}

### Physiological Consequences of Body Water Imbalance

#### Dehydration

Body water deficits can occur in all environments, either from inadequate water availability, insufficient voluntary intake to offset water losses in sweat and respiration, or excessive water loss from diuresis or diarrhea. Regardless of the specific process, water deficit or dehydration can reduce the ability of soldiers to perform mission-essential tasks in a timely and effective manner, thus increasing their likelihood of becoming medical casualties.

#### Symptoms

One of the earliest qualitative signs of dehydration is the development of thirst.\textsuperscript{1} With approximately 2\% body weight loss, vague discomfort develops, and the number of complaints increase. With additional water loss, soldiers can develop:

- flushed skin,
- heat oppression,
- weariness,
- sleepiness,
- impatience, and
- anorexia.

At 4\% loss of body weight, soldiers display signs of apathy, and might complain of muscle fatigue and nausea. At water deficits of 6\% body weight and greater, soldiers will likely display:

- dizziness,
- headache,
- dyspnea,
- tingling in limbs, and
- very dry mouth.

They might present with indistinct speech and the inability to walk.

#### Thermoregulatory and Cardiovascular Effects

Body water deficits increase the thermal strain of exercise in temperate and hot environments. Individuals performing the same physical task when dehydrated have higher core temperatures than they would if they were normally hydrated, and the magnitude of the core temperature increase is proportional to the body water deficit. Studies examining the core temperature response to graded water deficits report that core temperature increases 0.15°C to 0.20°C for every 1\% body weight lost.\textsuperscript{1,27–29} This relationship is maintained independent of exercise intensity\textsuperscript{30} and is not affected by changing the pattern of drinking.\textsuperscript{1,31} The magnitude of core temperature increase is, however, less in temperate versus warmer environments. In cold environments, dehydration does not seem to increase the risk of hypothermia; limited data available suggest that body temperature falls similarly during whole-body cooling, depending on if an individual is normally hydrated or dehydrated.\textsuperscript{32} Whether dehydrated persons are at increased risk of peripheral cold injury is controversial.\textsuperscript{33–35}

Dehydration exerts its effects on thermoregulation by altering the ability to dissipate heat to the environment. Both skin blood flow and sweating responses are affected. Fortney and colleagues\textsuperscript{36} reported that thermally induced dehydration increased the esophageal temperature threshold for cutaneous vasodilation and attenuated the increase in cutaneous blood flow per unit increase in body temperature. Dehydration also reduces peak cutaneous vasodilatation in both humans\textsuperscript{36} and nonhuman primates.\textsuperscript{37,38} Montain and colleagues\textsuperscript{39} found that thermally induced dehydration increased the esophageal temperature threshold for sweating and attenuated the increase in sweating per unit increase in body temperature. In addition, the magnitude of the sweating gain and sensitivity alterations increased as a function of body water loss, which is in agreement with the observation that temperature
increases in proportion to the water deficit.

Singular and combined effects of hypertonicity and hypovolemia contribute to modulating thermoregulation when an individual is hypohydrated. Hypertonicity, per se, will increase the esophageal temperature threshold for sweating \(^{36,40,41}\) and increase core temperature during exercise-heat stress. \(^{36,40,41}\) Similarly, the production of an isotonic hypovolemia with diuretic administration adversely affects cutaneous vasodilatation \(^{42}\) and sweating, \(^{43}\) and increases core temperature during exercise-heat stress.

Afferent signals responsible for the thermoregulatory effects of dehydration come from several anatomical areas. Osmoreceptor cells located in the preoptic/hypothalamic area are activated when intracellular volume declines. These cells affect the firing of thermosensitive neurons in the thermoregulatory control center. \(^{44,45}\) Cardiac mechanoreceptors or pulmonary baroreceptors, or both, also modulate the thermoregulatory response to exercise and heat stress because application of lower body negative pressure during heat stress augments heat storage independent of changes in blood volume or tonicity. \(^{46,47}\) These observations are consistent with the neurophysiological findings that osmotic and blood pressure stimuli modulate the firing of thermosensitive neurons in the preoptic and anterior hypothalamus. \(^{44}\)

The consequences of dehydration on the cardiovascular response to exercise have also been characterized. During submaximal exercise with little thermal strain, dehydration elicits an increase in heart rate and a reduction in stroke volume with little or no change in cardiac output relative to euhydrated levels. \(^{48}\) During more vigorous exercise, the increase in heart rate does not fully compensate for reductions in stroke volume, and cardiac output is reduced. \(^{49}\) In warm environments, the detrimental effects of dehydration are exacerbated. Experiments examining the effect of graded levels of water loss on the cardiovascular response to exercise report graded increases in heart rate \(^{1,27,28,30}\) and stroke volume reductions, \(^{28,30,48}\) with increasing water deficit. Cardiac output falls in a graded manner with water deficit \(^{28,30}\) because the increase in heart rate is not sufficient to offset stroke volume reductions.

**Effects on Physical Performance**

Dehydration in excess of 2% normal body mass has negative effects on morale and willingness to work. Comments from investigators working with soldiers during World War II illustrate how devastating dehydration can be (Figure 7-3). Adolph et al. \(^1\) reported that, in dehydrated soldiers, “walking was mechanical, and a matter of will power” and that soldiers “threatened to quit unless given water.” Eichna and colleagues \(^2\) found that tasks became much more difficult, and “acclimatized subjects who had performed a given task easily, energetically, and cheerfully” were “reduced to apathetic, listless, plodding men straining to finish the same task.” More recently, Strydom et al. \(^50,51\) reported that dehydrated men became lethargic and morose, and were aggressive and disobedient toward their superiors.

**Fig. 7-3.** (Left) Man falls out of formation as other troops keep marching. He has been overcome by heat exhaustion and collapses. (Right) Two first-aid men helping the GI who has been overcome by heat exhaustion. They have loosened his clothes and are giving him a drink of water. [Original caption] Photographs: Reproduced from the National Archives and Records Administration, Washington, DC, photo nos. SC-391634 (left) and SC-391635 (right).
Dehydration in excess of 2% body mass compromises physical performance. Exercise endurance time is shorter during both submaximal and maximal exercise, and less work is accomplished per unit of time when dehydrated beyond 2% body mass (−1.5 L for a 70-kg soldier) in temperate and warmer environments. Detrimental effects of dehydration afflict large and small muscle mass activities. In contrast, dehydration has little effect on muscle strength, at least up to 5% loss of body weight. Evidence also indicates that somewhat greater dehydration is necessary before endurance performance is affected in cool/cold climates.

Dehydration also reduces heat tolerance. In a 1992 study, scientists had subjects walk to voluntary exhaustion when either euhydrated or dehydrated (8% of total body water). The experiments were designed so that the combined environment (Ts = 49°C, relative humidity = 20%) and exercise intensity (47% maximal oxygen) would not allow thermal equilibrium; thus, heat exhaustion eventually occurred. Dehydration reduced tolerance time from 121 minutes to 55 minutes; but, more importantly, core temperatures at exhaustion were approximately 0.4°C lower when subjects were dehydrated. These findings suggest that dehydration not only impairs exercise performance, but also reduces tolerance to heat strain.

Hyperhydration

Because moderate levels of dehydration can be detrimental to soldier performance, it is important to consider whether overdrinking or taking substances to achieve hyperhydration or greater-than-normal body water would be beneficial for temperature regulation and exercise performance. Studies that directly expanded blood volume have usually reported decreased cardiovascular strain during exercise, but disparate results on heat dissipation and exercise-heat performance. Other studies examining the effect of overdrinking to produce a transient hyperhydration have found generally reduced heart rates during submaximal exercise, but disparate results regarding core temperature (reviewed in Sawka et al). Studies observing lower core temperatures were often confounded by lower core temperatures before exercise. When this effect was controlled, hyperhydration had no appreciable effect on thermoregulation during exercise.

Although many studies have attempted to induce hyperhydration by overdrinking water or water-electrolyte solutions, these approaches have produced only a transient expansion of body water. Greater fluid retention can be achieved with aqueous solutions containing small quantities of glycerol. Although an early report suggested that glycerol hyperhydration enhanced heat dissipation during exercise-heat stress, this finding has not been confirmed by subsequent investigations. In addition, this finding has not improved endurance exercise performance or exercise-heat tolerance.

Water Intoxication or Hyponatremia

Drinking too much can make soldiers sick. A relatively rare but clinically important problem for military personnel is the development of hyponatremia consequent to overdrinking water during training. From 1989 to 1998, 10 to 20 US Army soldiers were hospitalized yearly with symptomatic hyponatremia, and hyponatremia was the cause of at least one soldier’s death. The majority of cases occurred during warm weather training and afflicted soldiers in a basic training environment. Symptomatic hyponatremia occurs most often in soldiers and athletes who perform prolonged physical activities that produce (or are believed will produce) relatively high sweat rates and are sustained longer than 5 hours. The majority of cases have occurred during physical activities lasting longer than 8 hours.

Symptoms and Etiology

Symptoms of hyponatremia generally occur at serum sodium concentrations < 125 mEq/L and include the following:

- mental confusion,
- disorientation,
- malaise,
- weakness,
- nausea,
- transient neurological deficits,
- seizures, and
- coma.

The absence of hyperthermia excludes the diagnosis of heatstroke. Symptoms are most severe when sodium is diluted rapidly (ie, over hours rather than days). This condition is a consequence of the combined loss of sodium in sweat and failure to excrete the large amounts of hypotonic fluid that have been ingested. The net result is a dilution of body sodium. Retention of excess water is not from abnormal renal function, but rather extrarenal factors that suppress renal water excretion and/or inappropriate AVP levels. For example, Poortmans demonstrated that physical exercise reduces urine flow rate even in...
overly hydrated men. In the experiment, overdrinking before performing exhaustive exercise produced urine flow rates of 12 mL/min. Despite continuing to drink 200 mL of water every 20 minutes during vigorous exercise, the urine flow rate fell to 2 to 3 mL/min. This occurred likely because vigorous exercise reduces the glomerular filtration rate. In addition, various factors enhancing tubular sodium reabsorption causes isoosmotic reabsorption of water to increase. As a consequence of decreased glomerular filtration rate and increased water reabsorption, urine volume will decrease.

**Prevention**

Episodes of hyponatremia have, in most cases, been associated with excessive water intake relative to sweat losses. Soldiers—especially noncommissioned officers, training cadre, and junior officers—need to be educated that overdrinking is not beneficial (ie, it does not enhance thermoregulation or exercise capacity). The key to prevention is to ensure that volunteers drink only in amounts less than or equal to their sweating rate. Dehydration less than 2% body mass does not compromise performance; therefore, full fluid replacement is not essential during work. Because sodium is the major constituent of sweat (20–60 mEq/L), prolonged sweating can produce substantial sodium deficits. To prevent sodium depletion, soldiers should have access to regular meals. In work environments that produce prolonged, persistent sweating, salting food to taste is generally sufficient to prevent salt depletion. However, when conditions do not permit eating meals, adding small quantities of salt (−0.05% NaCl solution) to the water supply, including salt-containing beverages (eg, commercial sports drinks), or using commercially available salt tablets are viable options to replace salt losses.

**FACTORS INFLUENCING DAILY WATER REQUIREMENTS**

Several factors influence a soldier’s daily water requirements. This section summarizes the effect of environment, physical activity, body size, gender, and load carriage on daily water loss. However, these factors rarely occur independently, and it is their interaction that determines a soldier’s daily water needs.

**Environment**

The environment dictates the avenues of heat loss available. In cool and temperate environments, a substantial quantity of heat can be dissipated via radiation and convection. During moderate physical activity in temperate environments, approximately 50% of the heat produced can be dissipated via nonsweating means. In cold environments, almost 75% of the heat produced can be dissipated by nonsweating means. In contrast, in air temperatures 35°C and higher, virtually all heat produced must be dissipated by sweat evaporation. The greater demand on sweating in hot environments can substantially increase a soldier’s daily fluid requirements.

**Physical Activity**

A soldier’s daily water requirements increase as a function of the total calories expended per day (Figure 7-4). This occurs because sweat losses are dependent on exercise intensity and duration of effort. For example, in temperate conditions, moderate-intensity military tasks (~425 watts; 6.1 kcal/min) will elicit sweating rates of approximately 0.3 L/h, whereas hard work (~600 watts; 8.6 kcal/min) will elicit sweating rates approximately 0.7 L/h. The duration of physical activity also has a significant effect on water need. Although moderate-intensity work in temperate conditions might not elicit high rates of sweating (~0.3 L/h) when extended over an 8-hour period, a soldier’s daily fluid requirements increase an additional 2.4 L/d.

**Body Size and Gender**

Because men typically are heavier and sweat more profusely than women during physical activity, they will likely have larger daily fluid requirements. This occurs because the caloric cost of ambulatory activity increases as a function of body mass; therefore, larger persons expend more energy walking 1 mile than do smaller persons. Thus, men will expend more energy during marching, and thus produce more heat, than women. In addition, studies show that men have fewer sweat glands per unit area compared with women, but they produce more sweat per gland. As such, men will generally require larger quantities of fluid than women.

For ambulatory activities, rates of sweating are nearly proportional to the two-thirds power of body weight. Therefore, a 91-kg man will sweat approximately 30% more than his 59-kg companion walking at the same speed.
Load Carriage

The energy cost of marching with an All-Purpose Lightweight Individual Carrying Equipment (ALICE) pack and load-bearing equipment (LBE) is much greater than marching without it. Soldiers wearing a 31-kg ALICE pack and LBE expend 29% more energy to march 3.5 mph. Soldiers carrying a 49-kg ALICE pack–LBE ensemble expend 63% more energy to march at the same speeds without the packs. In temperate environments, the added energy cost of carrying the 31- or 49-kg backpack ensemble would increase the expected sweating rate from approximately 0.3 L/h without the pack to 0.6 and 1.1 L/h for the two packs, respectively. An additional factor affecting sweating requirements is the loss of effective surface area for evaporation of sweat, because the pack blocks sweating evaporation from the back. Most likely, this would further increase sweating beyond the sweating rate calculated from the added energy cost alone. Adolph et al reported that sweating rate increased 7 g/h/kg of backpack weight for packs weighing 10 to 20 kg.

IMPACT OF HOT ENVIRONMENTS ON FLUID REQUIREMENTS

In temperate environments, the daily fluid requirements of soldiers typically range from 2 to 5 L/d, depending on the intensity and duration of physical activities. However, as air temperature rises, daily fluid requirements can increase substantially. In extremely hot conditions, water requirements for soldiers performing primarily sedentary activities can increase from approximately 2 to 3 L/d to 5 L/d. Water requirements for soldiers performing heavy work or long hours of moderate work (4,200–5,300 kcal/d) can increase from 4 to 6 L/d in temperate environments and from 8 to 10 L/d in extremely hot environments.

Relative humidity can increase water requirements independent of ambient temperature. Although relative humidity has little impact on sweating and water requirements in temperate environments, high humidity conditions increase water requirements as much as twofold in warmer environments. When the humidity is high, the dramatic increase in sweating requirements underscores the tremendous water supply requirements posed when troops are deployed in tropical and desert climates.

Individuals exposed to hot environments generally drink insufficient fluids during physical activity to offset water lost from sweating. Heat acclimatization shortens the time delay between when sweating begins and when drinking is initiated. In addition, heat-acclimatized individuals drink more frequently and more closely match fluid intake with sweating rate; this results in less voluntary dehydration. During light exercise, heat-acclimatized soldiers can and often will drink sufficient quantities to sustain hydration. However, during moderate- to heavy-intensity exercise, drinking ad libitum generally replaces 50% to 70% of sweat losses, and deficits need to be addressed during rest breaks.

Clothing can have a significant effect on daily water requirements. Typically, clothing adds insulation and hinders vapor permeability, thus increasing the sweating rate (compared with wearing shorts and a T-shirt). The addition of backpacks and body armor increases the energy cost of locomotion and reduces the surface area available for heat transfer, thereby further increasing dependence on sweating. However, there are conditions in which clothing can actually aid in reducing water requirements. For example, in hot, arid environments, fully clothed soldiers wearing light, breathable clothing actually sweat less than minimally clothed men. During desert walks in the full sun, light, breathable fabric that reflects solar radiation can reduce sweating as much as 20%.

![Fig. 7-4. Estimates of daily water requirements for range of environmental conditions and energy expenditures.](image)
**Effect of Hot Environments on Thirst and Voluntary Dehydration**

Thermal stresses associated with hot environments are a positive stimulus for thirst and voluntary intake. It is not uncommon, however, for persons working in the desert to accrue water deficits. As discussed previously, the objective of drinking is to prevent water deficits from exceeding approximately 2% of normal body mass (e.g., ~1.5 L for a 70-kg soldier). This level of water deficit is associated with the onset of reduced performance. Any imbalance between sweating rate and voluntary intake will likely be more prevalent and of greater magnitude in persons unacclimatized to working in the heat. Greenleaf et al. revealed that volunteers matched water intake to sweating rate during repeated bouts of exercise-heat exposure. They did this by drinking earlier, and the volunteers drank more frequently during the 2-hour exercise-heat exposure period. The average volume consumed per drink did not change.

**Effect of Hot Environments on Water Delivery**

In tropical regions, water sources are often abundant (e.g., rivers, streams, lakes, ponds, wells, and local water systems). However, because of dense vegetation, poor ground transportation (via truck) can impair water distribution and increase reliance on aerial resupply. In desert regions, water sources are limited and widely dispersed. Although water needs are greatest in these hot environments, surface fresh water is almost nonexistent, and available subsurface water can vary from region to region. Lack of available water in desert environments increases water storage and distribution requirements.

**Hot Weather Water Requirements**

In hot, climatic extremes, daily water requirements for soldiers can range from 5 to 12 L/d. The Water Consumption Planning Factors study report (also known as the Potable Water Planning Guide), published by the US Army Combined Arms Support Command, recommends that each soldier be provided with 11.4 L of water per day. Therefore, in an established battlefield situation in which water supply is achieved, sufficient water should be available to sustain the water balance of each individual soldier.

### EFFECT OF COLD WEATHER OPERATIONS ON WATER REQUIREMENTS

A number of factors can increase fluid requirements during cold weather operations. One factor is the development of cold-induced diuresis. This phenomenon, first described more than 200 years ago, occurs when people become chilled during either cold water or cold air exposure. It is an osmotic diuresis and can increase urine water losses 2-fold above basal conditions. Although the precise mechanism is not known, generally it occurs as a consequence of increased central vascular pressure caused by peripheral vasoconstriction. Fortunately, diuresis seems to be self-limiting, because the rate of urine production declines with the development of dehydration.

A second factor is increased respiratory water loss from breathing cold, dry air. The magnitude of water loss is dependent on both the ventilatory volume and water vapor in ambient air. Because cold environments increase the water vapor pressure gradient between the lungs and the atmosphere, more water is lost through respiration in cold environments than in warm environments. The effect of cold temperatures on respiratory water loss, however, does not greatly increase daily fluid requirements.

A third factor is that wearing bulky, cold weather clothing could contribute to water loss. Military physical training activities can generate substantial metabolic heat that must be dissipated to prevent excessive elevations in body temperature. If clothing insulation is too thick for the activity level, then substantial sweating can occur. For example, during rest and light work, persons wearing protective clothing from the US Army Extended Cold Weather Clothing System are thermally comfortable and are able to dissipate much of their body heat through nonsweating means (Exhibit 7-1). However, during more vigorous activities, sweating rates can achieve levels in excess of 1 L/h. To minimize these unnecessary sweat losses, soldiers should be trained to use layering and open ventilation options in their clothing level to minimize sweat production during cold weather training.

A fourth factor that can affect water requirements is the added metabolic cost of movement in cold terrain. The addition of bulky clothing reduces mechanical efficiency and can increase the energy cost of a specific activity an additional 10% to 20%. The metabolic
cost of movement in soft snow can be 2.5 to 4.1 times greater than performing the same activity on a black-top surface.

**Effect of Cold Weather on Thirst and Voluntary Dehydration**

Investigations studying the effect of air temperatures on thirst and drinking behavior consistently report depressed voluntary drinking during cold weather activities.\(^{96,101,102}\) Experiments in rats demonstrate that this species will voluntarily dehydrate during cold exposure, but will manifest striking thirst when returned to a warm room.\(^{101}\) Similar observations have been made in humans.\(^{102}\) One strategy that has improved voluntary intake is the provision of warm drinks rather than cool drinks during cold exposure.\(^{103}\)

An additional cold weather problem occurs when individuals purposefully refrain from drinking to avoid having to urinate in the cold. This behavior typically occurs late in the day when soldiers try not to leave a warm tent or sleeping bag to urinate. If the mission scenario requires soldiers to rehydrate late in the day, their behavioral decision to refrain from drinking adequate quantities of fluid can lead to persistent dehydration during the next day’s activities. One solution is to ensure that soldiers drink regularly during cold weather activities to avoid development of large water deficits. Snack breaks can also stimulate additional fluid intake. This particular strategy will help soldiers to avoid rehydration with large quantities of water before bedtime and reduce the likelihood of their having to get up and urinate during set sleep periods.

**Effect of Cold Weather on Water Delivery**

The most important factor regarding fluid intake in the cold is the logistical constraint of potable water delivery. In arctic regions, melting snow and ice will provide only enough water for emergency use by individuals and small units. Because of the extensive fuel requirements to melt snow and ice, this is an impractical water source for larger military units. However, the primary water source is unfrozen water underlying frozen rivers, lakes, and wells constructed by civilians and military personnel. The limited availability of water sources greatly increases distribution requirements, and storage and distribution elements must be augmented with specialized equipment to prevent or retard freezing of packaged water. If small units must rely on melting snow and ice for their water supply, the provision of adequate fuel is essential. In addition, the water must be adequately treated to ensure that it is potable.

**Daily Water Requirements**

Studies examining the voluntary intake of water by soldiers during field maneuvers report daily fluid intakes ranging from 2 to 4 L/d.\(^{104-106}\) However, when energy expenditures are high, human water needs can range from 4 to 6 L/d. Accordingly, the Water Consumption Planning Factors study report recommends the daily provision of 7.6 L of drinking water per soldier for tactical theater and field training exercises in arctic environments.\(^{93}\)

**EFFECT OF HIGH-ALTITUDE OPERATIONS ON WATER REQUIREMENTS**

Military operations in mountainous areas can affect short- and long-term water balance. For example, acute exposure to moderately high altitudes can often produce a self-limited reduction of body water resulting from reduced fluid intake and increased urine volume. Other factors can also affect voluntary water
intake and daily water requirements, including the following: (a) symptoms of anorexia and hypodipsia; (b) increased respiratory water loss from breathing cold, dry air; and (c) cutaneous evaporative losses with physical activity.

Effect of High-Altitude Operations on Water Balance

Unacclimated soldiers exposed to moderate, high-altitude hypoxia (3,500–5,000 m) typically become somewhat dehydrated (losing approximately 1–2 L of water from the body, which equals 3% to 5% of total body water) during the first 1 to 3 days of exposure.\(^{107,108}\) This water deficit results in decreased extracellular volume, decreased plasma volumes, and some loss of intracellular water. It occurs as a consequence of arterial chemoreceptor activation, which produces a self-limited natriuresis and diuresis, as well as suppressed thirst and reduced voluntary water intake.\(^{107}\) Attempting to overdrink to prevent the water deficit is not recommended. Diuresis and polyuria are considered beneficial adaptations because (a) increased plasma hemoglobin concentration increases arterial oxygen content and improves tissue oxygen delivery; and (b) people who develop natriuretic and diuretic responses have less severe symptoms and less incidence of acute mountain sickness.\(^{107}\)

The relative dehydrated state produced by moderate- to high-altitude exposure can persist for several weeks. Studies examining water balance in humans exposed to elevations of 3,500 to 5,334 m report persistent reductions in total body water for up to 14 days.\(^{108,109}\) Over time, however, blood volume increases as the volume of red blood cells increases at altitude, with plasma volume remaining reduced or returning to sea-level values.\(^{107}\) Observation of increased plasma volume over time suggests some restoration of total body water with chronic hypoxic exposure.

Effects of Hypoxia on Thirst and Voluntary Water Intake

It is not uncommon for voluntary water intake to decrease approximately 1 L/d during the first 1 to 2 days of moderate, high-altitude exposure.\(^{108}\) Suppressed voluntary water intake does not persist because, generally, daily water intake returns to predeployment levels within the first week of altitude exposure.

Other Factors Associated With High-Altitude Operations That Affect Water Requirements

There is a general belief that increased respiratory evaporative water losses accompanying moun-
tainous operations significantly affect daily water requirements.\(^{110}\) This may be true at high-altitude extremes; for example, Pugh\(^{111}\) reported that climbers at 5,500 m had respiratory evaporative water losses of 2.9 g of water per 100 L (body temperature and pressure, saturated with water) of ventilation. However, at more modest elevations, the combined effects of colder air temperatures, lower humidity, and the higher ventilation rates relative to energy expenditure do not add appreciatively to daily water requirements. Over a broad range of energy expenditures (3,500–7,000 kcal/d), the estimated net respiratory water losses at 2,200 to 3,100 m are very similar to the estimated respiratory water losses at sea level.\(^{110}\) Deployment to 4,300-m altitude will increase daily water requirements approximately 200 to 300 mL/d to compensate for added respiratory water loss.

Cutaneous sweat losses in soldiers working at low, moderate, or high altitudes depend on clothing insulation, ambient weather conditions, and absolute exercise intensity and duration. As in cold weather operations, clothing insulation at high altitudes must be matched to heat production to keep soldiers warm while preventing excessive heat storage and sweat losses. However, vigorous physical activity can produce relatively high rates of sweating and increase daily water requirements.

Effect of High-Altitude Operations on Water Delivery

Water supply in mountainous regions can come from lakes, streams, and local water supplies. Because mountain operations are often associated with cold weather, the same restraints can exist as those described for cold weather operations. An added factor is that high altitude increases the time required to purify water by boiling it. Therefore, if military units rely on melted snow to acquire water, this can have a significant effect on the time required to obtain potable water, as well as on the fuel requirements of small units.

Water Requirements

Military groups operating in high-altitude environments have generally sustained hydration by drinking 4 to 5 L/d when performing primarily sedentary activities.\(^{104,112}\) The Water Consumption Planning Factors study report recommends the provision of 5.6 to 7.6 L/d of drinking water per soldier.\(^{95}\) Therefore, if supply lines are maintained as planned, the water supply should be sufficient to sustain hydration during military maneuvers.
EFFECT OF WATER IMMERSION ON WATER REQUIREMENTS

Water immersion increases central venous pressure and produces a transient diuresis and natriuresis. The magnitude is dependent on water depth, temperature of the water, and the initial state of hydration. The quantity of water lost, however, is not sufficient to greatly increase daily water requirements. However, because immersion blunts the thirst response, it may also affect voluntary fluid intake and the ability to sustain hydration during prolonged operations in water environments. Whether prolonged partial immersion would sufficiently affect drinking behavior and the ability to sustain hydration has not been studied.

BARRIERS TO REHYDRATION

Water Availability

Lack of potable water is probably the greatest barrier to sustaining hydration. If water is not available, rehydration cannot take place and soldiers will suffer. Just having potable water, however, is not sufficient. Water must be made available to the troops. Soldiers at work are more likely to refrain from drinking water if they have to travel some distance to obtain it. This is especially true in desert and arctic conditions, because both weather extremes diminish the desire to do additional work.

The collapsible bladder with drink-tube hydration systems provides a practical example of how availability increases voluntary fluid replacement. With these systems, the soldier can drink on the go in a near hands-free manner (Figure 7-5). When carrying a traditional 0.9-L rigid plastic canteen, the soldier cannot easily access the canteen on the go—particularly when carrying an approach load—and this increases the need to take rest breaks to drink. Although historically the collapsible-bladder hydration systems suffered from poor durability and were difficult to keep clean, advances in the manufacturing process have lessened these deficiencies.

Palatability of Water

If water has an unpleasant taste or odor, voluntary intake will be reduced. Efforts should be made to make water as palatable as possible. Factors that affect palatability include odor, taste, temperature, color, and turbidity of the fluid. The odors and tastes found in water are most commonly caused by algae, decomposed organic matter, and dissolved gases. Chlorination and iodination both add taste to water and can decrease palatability. Water color is derived from colored substances (eg, vegetative matter that is dissolved from roots, leaves, and humus) or from inorganic compounds (eg, iron and manganese salts). Turbidity is caused by suspended clay, silt, organic and inorganic matter, and plankton and other microorganisms. Warm water tastes flat and augments any odors and flavors in it. Water treatment and disinfection remove much of the particulate matter and reduce water color. Cooling water further suppresses odors and tastes, and makes water more palatable.

Fig. 7-5. Hands-free drinking. Competitor Specialist Heyz Seeker gets a drink from a hydration device during the Urban Warfare Orienteering Course event of the Department of the Army Best Warrior competition at Fort Lee, Va. Photograph: Courtesy of T Anthony Bell, Fort Lee Public Affairs Office.
During the Persian Gulf War (1990–1991), the US military introduced bottled water to combat nonpalatable water. Although bottled water is expensive to buy and deliver to the troops, particularly in warm weather conditions, it avoids the taste issues associated with mass-produced water containing residual chlorine. Flavor additives can mask the unpalatable taste of chlorine, but they should be added to the water just prior to consumption because these additives can completely destroy the effectiveness of the chlorine.

Gastric Emptying

A potential barrier to sustaining hydration is gastric emptying and intestinal absorption. Evidence to date, suggests that, under most conditions faced by the fighting soldier, neither gastric emptying nor intestinal absorption should hinder the ability to sustain hydration during deployment. The stomach and small intestine function extremely well under conditions of exercise and environmental stress. Furthermore, neither gastric emptying nor intestinal absorption are delayed or impaired by exercise intensities ranging up to 70% maximum oxygen uptake, even during prolonged, sustained physical activity. It should be recognized, however, that there is a great deal of individual variability in rates of gastric emptying and intestinal absorption. Therefore, some soldiers may be less tolerant of drinking large volumes of fluid, and there are other soldiers who are so tolerant that they can actually drink fast enough to make themselves sick (see section on Water Intoxication or Hyponatremia). Scheduled rest breaks and adequate mealtimes should be included to provide time to rehydrate.

Lost Solutes

Complete restoration of a fluid volume deficit cannot be achieved without electrolyte replacement (primarily sodium) in food or beverages. Electrolytes, primarily sodium chloride and, to a lesser extent, potassium, are lost through sweat during physical activity. The concentration of sodium in sweat averages approximately 30 to 50 mEq/L, but can vary, depending on an individual’s state of heat acclimatization, diet, and hydration. Furthermore, the amount and composition can also vary, contingent on exercise intensity and environmental conditions. Potassium concentration in sweat is approximately 6 g/d for the active soldier. In temperate conditions, sodium chloride concentration in sweat can range from 2 to 13 g/d, averaging approximately 6 g/d for the active soldier. Potassium losses will range from 0.1 to 0.9 g/d, averaging approximately 0.5 g/d for the active soldier. In hot environments, sodium chloride and potassium losses can exceed 17 and 1.9 g/d, respectively. Considering that three Meals, Ready-to-Eat contain 12.6 g of sodium chloride and 2.7 g of potassium, and that typically only two Meals, Ready-to-Eat are provided during field operations, there are many situations in which supplemental salt may be required to offset the sodium chloride lost in sweat. Typically, this deficit can be managed by salting food to taste. Figure 7-6 provides estimates of expected daily sodium losses consequent to working in different environments.

STRATEGIES TO SUSTAIN HYDRATION IN HARSH ENVIRONMENTS

Do Not Skip Meals

Studies on soldiers working in the desert clearly demonstrate that the majority of daily fluid intake occurs at mealtime. As illustrated in Figure 7-7, soldiers working in the heat voluntarily dehydrated themselves during work periods, but made up the water deficit during mealtime. This same pattern of drinking has since been confirmed by others. This observation is important because meals are a valuable time for
Water Requirements and Soldier Hydration

rehydration and maintenance of fluid balance (Figures 7-8 and 7-9). They also provide a source of solutes to offset the electrolytes lost during perspiration. As discussed previously, if missing solutes are not replaced, complete rehydration cannot be achieved.

Make Time to Drink

Soldiers will often underdrink voluntarily relative to the perspiration they produce during work. Rest breaks provide an opportunity for their fluid intake to catch up with their deficit. This is especially relevant when work and weather conditions produce sustained, profuse sweating. To achieve high rates of rehydration, it is advantageous to maintain a high gastric volume, because the speed in which a bolus of fluid leaves the stomach falls exponentially as the stomach volume decreases. A relatively full stomach and high rates of gastric emptying can be achieved by frequently drinking small amounts of fluid during work.114

Maximize Palatability

How a drink tastes is a major determinant of the amount of drink consumed. If the provided water tastes disagreeable, soldiers will drink less and will endure greater dehydration.1 Many factors play a role in palatability, including cultural background, previous experience with the drink, and time of day. Even per individual, palatability is not constant. The

Fig. 7-7. Changes in body weight of one researcher during a day in the desert. The loss was more rapid in warmer hours and fastest during an afternoon walk, reflecting change in evaporative water loss with conditions of activity and exposure. Most of the fluid was taken with meals.


Fig. 7-8. US Army Air Force personnel in Tunisia consuming their rations from defensive positions (March 7, 1943). The largest daily fluid intake is generally associated with consumption of meals.

Photograph: Reproduced from the National Archives and Records Administration, Washington, DC, photo no. 208-AA-2U-7.

Fig. 7-9. Nutrient on-the-move delivery system attached to standard Army hydration devices. This new system, developed by researchers at the US Army Research Institute of Environmental Medicine, provides the opportunity for soldiers to flavor their water, combined with various drink mixes, and add nutrients (eg, carbohydrate mixes).

The decrease in pleasantness can be specific to a particular drink. Therefore, if the goal is to increase voluntary fluid intake, then switching to a different drink can help to stimulate fluid intake. Rolls and Rolls\textsuperscript{116} found that persons offered a choice of three different flavors drank 22% more than when no flavored drinks were provided, and they consumed more of the flavored beverage than the nonflavored beverage.

Adding sweeteners to drinks leads to increased fluid intake.\textsuperscript{117} Adding too much sugar can decrease acceptability during physical activity. Trained endurance athletes reported more symptoms of nausea and fullness when drinks contained 12% glucose compared with drinks containing 6% glucose or water.\textsuperscript{118}

Carbonated beverages can be pleasurable with meals or when sedentary, but they make a poor fluid replacement beverage during activity. Sohar and colleagues\textsuperscript{119} found that soldiers drank less of the carbonated beverages than either water or flavored beverages. Soldiers who drank the carbonated beverages complained that carbonation made it difficult to drink large quantities of fluid.

Temperature of the preferred drink depends on a number of factors, including culture and learning,\textsuperscript{120} climatic conditions, and the physiological state of the individual.\textsuperscript{121} In hot and temperate environments, cool drinks increase voluntary intake.\textsuperscript{89,122} Drink temperatures of 15°C to 20°C seem optimal when persons

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### TABLE 7-3

**FLUID REPLACEMENT AND WORK/REST GUIDELINES FOR WARM WEATHER TRAINING CONDITIONS**\textsuperscript{*}

<table>
<thead>
<tr>
<th>Heat Category</th>
<th>WBGT\textsuperscript{1,4} Index (°F)</th>
<th>Easy Work</th>
<th>Moderate Work</th>
<th>Hard Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (green)</td>
<td>78–81.9</td>
<td>50/20 min</td>
<td>30/30</td>
<td>10/50</td>
</tr>
<tr>
<td>2 (yellow)</td>
<td>85–87.9</td>
<td>30/30</td>
<td>20/40</td>
<td>10</td>
</tr>
<tr>
<td>4 (red)</td>
<td>88–89.9</td>
<td>30/30</td>
<td>20/40</td>
<td>1</td>
</tr>
<tr>
<td>5 (black)</td>
<td>&gt;90</td>
<td>20/40</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

**Easy Work**
- Weapon maintenance
- Walking on hard surface at 2.5 mph, <30-lb load
- Manual of arms
- Marksmanship training
- Drill and ceremony

**Moderate Work**
- Walking in loose sand at 2.5 mph, no load
- Walking on hard surface at 3.5 mph, <40-lb load
- Calisthenics
- Patrolling
- Individual movement techniques (ie, low crawl, high crawl)
- Defensive position construction

**Hard Work**
- Walking on hard surface at 3.5 mph, ≥40-lb load
- Walking in loose sand at 2.5 mph with load
- Field assaults

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\textsuperscript{*} Applies to average size and heat-acclimated soldier wearing battle dress uniform in hot weather.

\textsuperscript{1} If wearing body armor, add 5°F to WBGT index in humid environments.

\textsuperscript{2} If wearing nuclear, biological, and chemical clothing (MOPP 4), add 10°F to WBGT index.

\textsuperscript{3} Work/rest times and fluid replacement volumes will sustain performance and hydration for at least 4 hours of work in the specified heat category. Fluid needs can vary based on individual differences (± \(\frac{1}{4}\) qt/h) and exposure to full sun or full shade (± \(\frac{1}{4}\) qt/h).

\textsuperscript{4} Rest means minimal physical activity (sitting or standing), accomplished in shade, if possible.

\textsuperscript{5} CAUTION: Hourly fluid intake should not exceed 1\(\frac{1}{2}\) quarts.

\textsuperscript{6} Daily fluid intake should not exceed 12 quarts.

\textsuperscript{7} No limit equals no limit to work time per hour (up to four continuous hours).

need to drink large volumes of fluid. In cold environments, voluntary intake is enhanced when drinks are warmed. In both environmental extremes, the dehydration-induced drive to drink will overcome any initial resistance to drink warm or very cold water.

Minimize Body Water Losses

There are several behavioral actions that soldiers can take to reduce sweat losses and maximize fluid retention. For example, in hot, arid environments, sweating rates can be reduced by working at night. During daylight hours, sweating rates can be reduced by covering the skin with light, vapor-permeable clothing. In cold environments, matching clothing insulation and/or clothing ventilation to the rate of heat production reduces the need for sweating to dissipate heat. Drinking small quantities of fluid frequently results in less urine production than drinking large quantities of fluid less frequently. Similarly, adding small quantities of salt to fluid-replacement beverages improves fluid retention compared with drinking water only, particularly when many hours of labor separate meals. There is no evidence that heat acclimation promotes water conservation; in fact, acclimation leads to earlier onset and more profuse sweating. Therefore, behavioral strategies are the best solution for minimizing water turnover.

Provide Education

Troop education on the importance of hydration is essential to deployed soldiers. Military planners and logistics personnel must ensure that adequate quantities of potable water are available. Small unit leaders should maximize delivery and availability of potable water to the soldiers. Therefore, these soldiers must understand the importance of drinking, making time to drink, and drinking the right amount.

As previously discussed, dehydration in excess of 2% body weight can have detrimental effects on troop performance. Thus, it is important that soldiers make time to drink during physical activity and drink sufficient quantities to minimize the likelihood of dehydration. It is not essential that soldiers fully offset sweat losses during physical activity. They can make up for any water deficit during rest breaks and at mealtime. The best method to prevent excessive dehydration during physical activity is to begin drinking early and continue drinking small amounts of water every 15 to 20 minutes of exercise.

Table 7-3 provides current Army hot weather guidance for fluid replacement in troops in training environments where work:rest ratios are practical for preventing heat injury. The amounts in each cell reflect the expected hourly fluid intake to fully replace all sweat lost during activity. Thus, the numbers in each cell are the average predicted sweating rates for each activity level and environmental condition. Because there is considerable variability between individuals, the numbers in each cell must be considered as approximates. As noted in Table 7-3 footnotes, actual sweating rates (and 100% fluid replacement) may vary between individuals by ±\(\frac{1}{4}\) quart per hour. Similarly, the work:rest ratios are a guide to approximately how much time should be dedicated each hour to work versus rest (assuming work will be sustained for several hours) to prevent body core temperatures from reaching levels associated with premature fatigue and heat exhaustion. Table 7-3 also specifies an upper limit for hourly (1.5 quarts) and daily (12 quarts) water intake to provide a safeguard against overdrinking and developing water intoxication (hyponatremia) during training.

SUMMARY

It has long been known that individuals can survive much longer without food than they can without water. Only in recent decades has science been able to quantify the factors that influence the body’s ability to maintain optimal water levels and the physiological consequences of water imbalance. This chapter has presented information to assist the caregiver—whether physician, medic, unit leader, or fellow soldier—in understanding the influence of environment, physical activity, body size and gender, and load carriage in maintaining water balance. In the not-so-distant past, a lack of understanding of these complex systems led to the deaths of thousands of military personnel in various campaigns. Until science (through the development of biometrics) can accurately and instantly evaluate the water balance of every soldier, it remains the responsibility of each individual—as well as support personnel—to be vigilant in recognizing the potential for and the development of water imbalance situations and to effectively institute rehabilitative measures.
REFERENCES


