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Sustaining Hydration in Hot Weather

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Summary

Maintenance of water and electrolyte balance is important for sustaining optimal performance. Dehydration produces greater thermal and cardiovascular strain during prolonged work; with the magnitude of added strain proportional to the magnitude of water loss. Dehydration also degrades morale and the desire to work. Body water deficits of as little as 2% normal body mass have been accompanied by impaired cognitive and physical performance. Furthermore, water deficits of 5% to 7% of normal body mass are generally associated with dyspnea, headaches, dizziness, and apathy.

This presentation will summarize work that the U.S. Army Research Institute of Environmental Medicine has been doing to sustain proper hydration of soldiers during training.

Military Doctrine and Hydration

For the past 15 years, the U.S. military doctrine has taught the soldier that hydration is essential for health and performance, and soldiers should drink frequently to prevent heat injury. The warfighter is encouraged to view water as a tactical weapon. The doctrine further teaches the soldier that if they avoid dehydration they will prevent heat injury and be better prepared to perform their mission. The emphasis on preventing dehydration has led the U.S. Army to adopt a one-size-fits-all drinking schedule for hot weather training, and mandatory or enforced drinking practices in the regimented training environment (e.g., basic training).

The emphasis on drinking as a heat injury prevention practice has been associated with a relatively low incidence of hospitalizations from heat illness. As illustrated in Figure 1, with the exception of the time period encompassing the Gulf War conflict, the rate of hospitalizations from heat illness over the past decade has been below 50 cases per 100,000 soldier-years.

During the same period, however (Figure 1), there has been an increased incidence of hospitalizations from hyposmolality and hyponatremia, with incidence rates of approximately 10 cases per 100,000 soldier years during the early to mid 1990s. In 1997, The U.S. Military realized the potential medical consequences of hyponatremia and overhydration when a young healthy soldier died consequent to excessive water intake during basic training (2). The death of this young man as well as an outbreak of other less severe symptomatic hyponatremia cases at Fort Benning, Georgia, led to an investigation of the training practices at Fort Benning as well as the Army. Participants in this investigation were staff from the U.S. Army Center for Health Promotion and Preventive Medicine, The U.S. Army Research Institute of Environmental Medicine, as well as staff of Martin Army Community Hospital, Fort Benning.

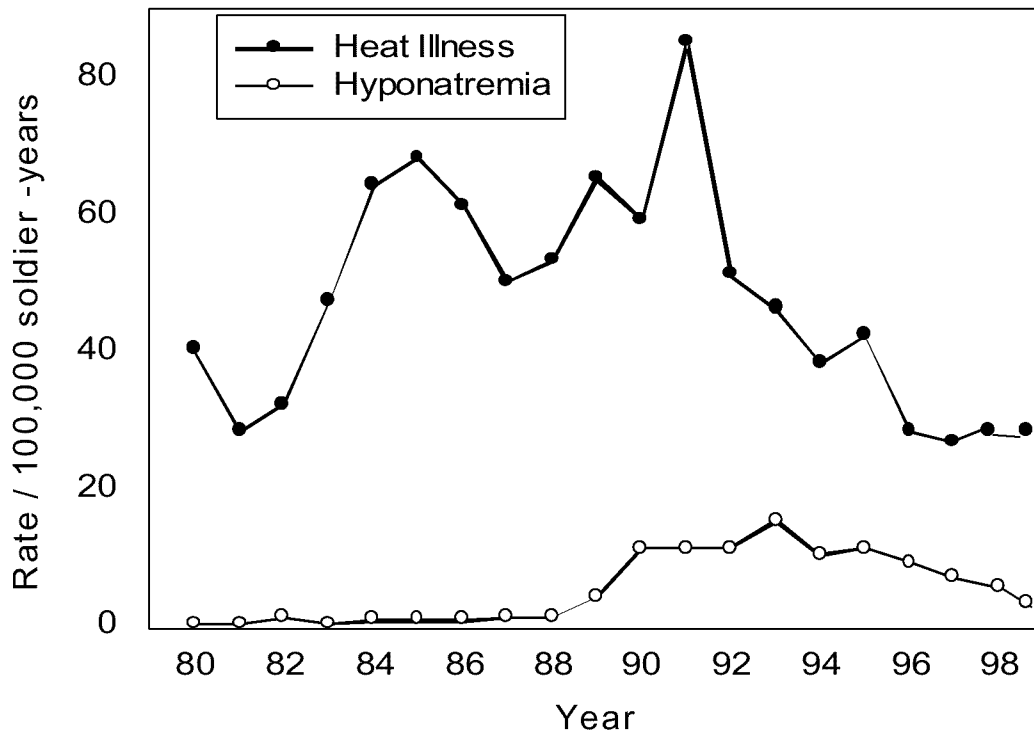


Figure 1. Army Hospitalizations due to Heat Illness & Hyposmolality / Hyponatremia 1980 - 1999

Hyponatremia

The term hyponatremia is strictly defined as a serum sodium level below 135 mEq/liter. However, the term is also used clinically to refer to the syndrome that can occur when there is rapid lowering of blood sodium usually to levels below 130 mEq/liter. In 57 case reports in the literature, serum sodium concentrations at presentation averaged 121 mEq/liter and ranged from 109-131 mEq/liter (6). Signs and symptoms of hyponatremia include confusion, disorientation, mental obtundation, headache, nausea, vomiting, aphasia, incoordination, and muscle weakness. Complications of severe and rapidly evolving hyponatremia include seizures, coma, pulmonary edema and cardiorespiratory arrest. While the condition is generally treatable without long term sequelae, death has occurred (2,7).

The symptomatic hyponatremia of exercise arises consequent to prolonged work (typically longer than 6 h) where sweating is the primary means of dissipating heat. As sweat not only contains water, but small quantities of electrolytes, there is a progressive loss of water, sodium, chloride, and potassium. Sweat electrolyte losses contribute to the development of the syndrome, particularly if sweat sodium losses are high. The condition may also occur when individuals consume low sodium or sodium-free water in excess of sweat losses during and/or shortly after completing exercise. In either case, the reduction in solute concentration in the extracellular fluid (ECF) promotes movement of water from the ECF into cells. If this fluid shift is of sufficient magnitude, and occurs rapidly, it can congest the lungs, swell the brain and alter central nervous system function. Figure 2 presents the physiological consequences of hyponatremia.

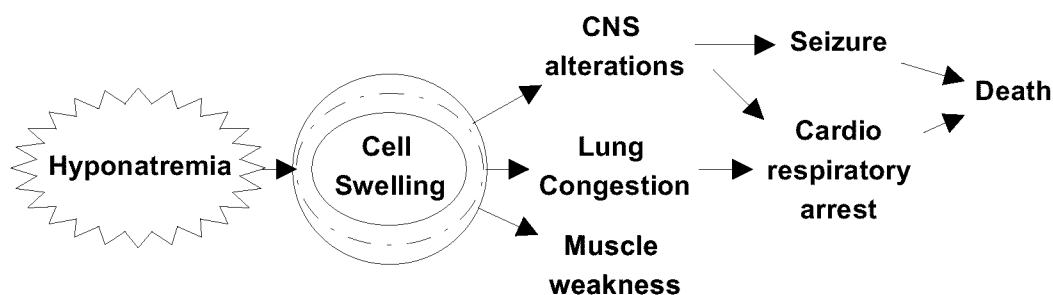


Figure 2. Physiological consequences of hyponatremia

To identify the factors that contributed to the outbreak of symptomatic hyponatremia in the U.S. Army and in particular at Fort Benning, Georgia, the medical records for all cases that occurred during the 1996 and 1997 training periods were obtained and a descriptive analysis was performed (1,7). Examination of the case histories of 17 soldiers hospitalized at Ft. Benning for hyponatremia revealed that all cases were from the student population (i.e., basic trainees). Seventy-seven percent of cases occurred during the first 4 weeks of training and the soldiers were generally healthy the days preceding becoming ill. All were associated with excessive water intake during training compared to water intake requirements predicted based on exercise intensity and weather conditions (3) (8). The excessive water intake was not due solely to voluntary intake or scheduled enforced drinking. Poor medical management also contributed to excessive fluid intake. When soldiers reported that they did not feel well, supervisory personnel often treated the symptoms by forcing additional hydration.

The consultation team recommended two revisions to training practices at Ft. Benning. First, they recommended that the guidelines in use at Ft. Benning be revised to provide more appropriate guidance on fluid intake during activity. Further, the committee also recommended that medical evacuation procedures be revised to more rapidly remove soldiers from training when they exhibited heat illness symptoms.

The fluid intake guidance in use prior to the soldier's death provided recommendations for hourly work and rest as well as drinking when training was conducted in hot weather. The old guidance took into account only the weather conditions and not exercise intensity. It was decided that the new guidance should recommend hourly work and fluid intake based both on the climate and exercise intensity. In addition, upper limits to hourly fluid intake and daily fluid intake should be included in the revised drinking guidance.

Revision of Fluid Replacement Guidelines

To construct the new fluid replacement guidelines, we first used the USARIEM heat strain model (8) as well as the Scenario model (3) to predict hourly work duration and the sweating rates for light, moderate and hard work (250, 425 and 600 Watts) under hot weather conditions ranging from 30 to 35°C wet bulb globe temperature. A table providing hourly work: rest recommendations as well as recommended water intake for three levels of work intensity for 5 hot weather categories was then generated. The predictions were then tested in a series of laboratory experiments where soldiers worked and drank as specified in the revised guidelines for a range of weather conditions. The table was then adjusted as necessary. The specific details of the modeling effort and the validation experiment are published elsewhere (5).

To determine if the revised guidelines had the desired effect of limiting incidence of overhydration but not promoting dehydration, blood samples and body weights were measured before and after 8-12 hour of military training under the old and new fluid replacement guidelines (4). The investigation was performed in two phases, August-September in 1997 and July-August, 1998. A total of 613 soldiers participated in the investigation. All were members of fourteen training platoons engaged in military basic training (six platoons in 1997 and 8 in 1998). The platoons were selected based on their training plans to include different

activities with a wide variety of metabolic rates. Daily wet bulb globe temperatures averaged $27\pm 2^{\circ}\text{C}$ (range $23\pm 2^{\circ}\text{C}$ to $33\pm 2^{\circ}\text{C}$) and $27\pm 1^{\circ}\text{C}$ (range $20\pm 1^{\circ}\text{C}$ to $30\pm 1^{\circ}\text{C}$) in 1997 and 1998, respectively. Each platoon was studied on one occasion. In each phase, the leaders and soldiers had received instruction on the respective water replacement guidelines by their instructors and medical officers earlier in the summer. The platoons performed activities according to training schedule and consumed fluid ad libitum or as directed by the platoon leader. The investigative staff did not enforce the guidelines in 1997 or 1998 data collection periods.

The results of this comparison suggest that the revised fluid replacement guidelines are reducing the incidence of overhydration among the training population. When training under the old guidelines, plasma sodium levels modestly declined from morning to afternoon (137.5 ± 1.6 mEq/liter to 137.1 ± 2.0 mEq/liter). Under the new guidelines, plasma sodium levels were initially higher ($P<0.05$) than under the old guidelines and modestly increased during training (139.0 ± 1.7 to 139.4 ± 2.15 mEq/liter). There was also a lower incidence of sodium levels falling greater than 2 mEq/liter (1 sd from the mean) under the new fluid replacement guidelines (Figure 3). Fifteen percent (42 of 273) of soldiers training under the old guidelines had greater than 2 mEq/liter reduction when training under the old guidelines while only 8% (22 of 277) of soldiers had greater than 2 mEq/liter reduction under the new guidelines ($\chi^2=26.4$; $P<0.05$).

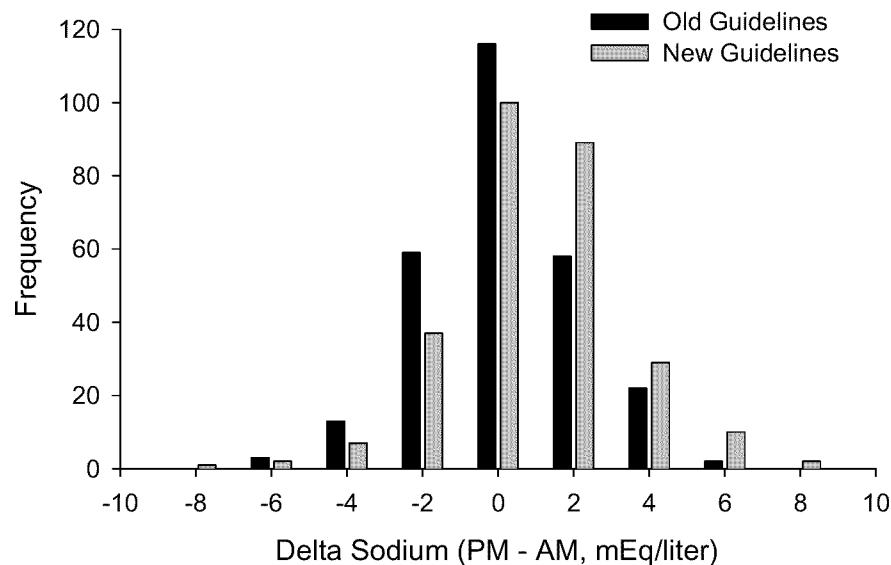


Figure 3. Frequency distribution of plasma sodium change when drinking using the old and new fluid replacement guidelines

Body mass changes between the two populations also support the contention that the revised fluid replacement guidelines improved hydration practices. The soldiers studied in 1997 had a body weight increase during the training day (75.2 ± 10 kg to 76.5 ± 9.9 kg). Less than 1% of the subjects lost more than 3% of body mass, whereas 30% of soldiers gained greater than 3% of their initial body mass during the training day. In contrast, the soldiers studied in 1998 had a smaller body mass gain (74.6 ± 10.6 kg to 75.0 ± 10.7 kg) during the training day and fewer soldiers gained greater than 3% of their initial body mass during the training day (4 of 311 soldiers; 1.6%). Training under the revised guidelines did not appear to increase incidence of dehydration (based on body mass changes) as less than 1% of soldiers had a body mass loss greater than 3% over the training day.

Another way to assess the effectiveness of the fluid replacement guidelines is to look at the incidence of hyponatremia hospitalizations since the revisions were put into effect. Figure 4 presents the incidence of hyponatremia / overhydration hospitalizations from 1997 to 1999 for U.S. Army posts that had 2 or more cases of hyponatremia in 1997. Since the introduction of the guidelines, there has been a progressive reduction in the number of hospitalizations (9).

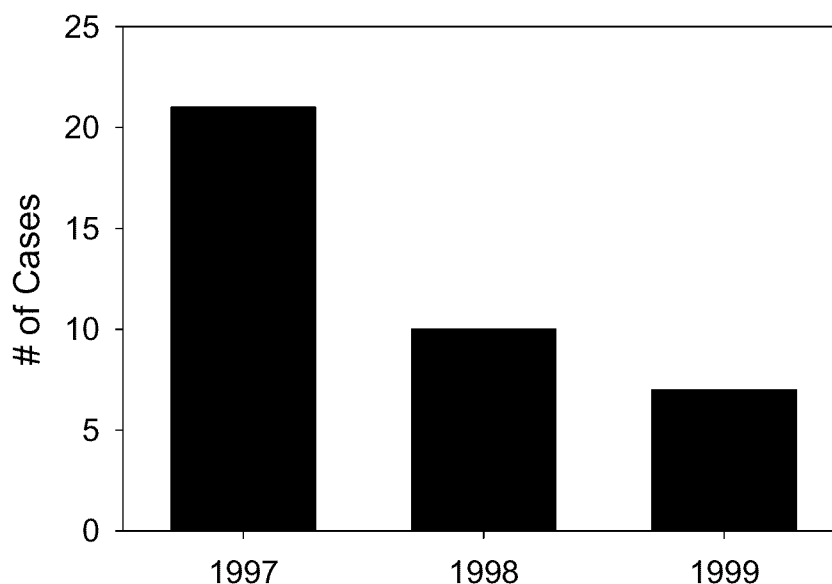


Figure 4. Hyponatremia / overhydration hospitalizations from 1997-1999 for U.S. Army Posts have 2 or more cases in 1997

Sustaining Hydration in Combat

In the field or combat environment, hourly drinking rate guidance is not as relevant as planning for daily water requirements. Our mathematical models enable us to predict daily water requirements. However, we still don't know if these estimates are valid or whether fluid intake matches the predicted requirement. Historically, researchers studying fluid intake in field training settings have had to rely on canteen exchange to look at individual soldier fluid intake. This can lead to error as soldiers may modify their drinking behavior when they know their intake is being monitored. A new type of canteen system available now may help address whether actual fluid intake matches predicted requirements and to carefully study factors that influence drinking behavior. This system consists of a collapsible bladder, a drinking tube and mouthpiece.

We have taken a commercial bladder type canteen with drink tube, and instrumented the drink tube with a flow meter. The output of the flow meter is sent to a microprocessor and stored for later processing. We call the system the Drink-O-Meter, and from it, it is possible to record when someone takes a drink, the volume they consume each drink, and the cumulative total consumed.

The Drink-O-Meter produces very linear and valid results when the drink velocity exceeds 9 ml per second (Figure 5, Left). To assess the accuracy of the device for measuring fluid consumption, seven trials were performed in which participants drank ad libitum from the instrumented canteen for several hours. Figure 5 (right) presents the difference between the volume recorded by the Drink-O-Meter and the actual volume consumed. The Drink-O-Meter differed from the actual volume by 16 ± 26 ml ($1.6 \pm 2.6\%$). Therefore, the device can accurately measure ad libitum fluid consumption. Furthermore, the flow properties of the flowmeter are appear adequate for measuring human drinking behavior as only 1 of 7 trials resulted in underprediction of fluid consumption.

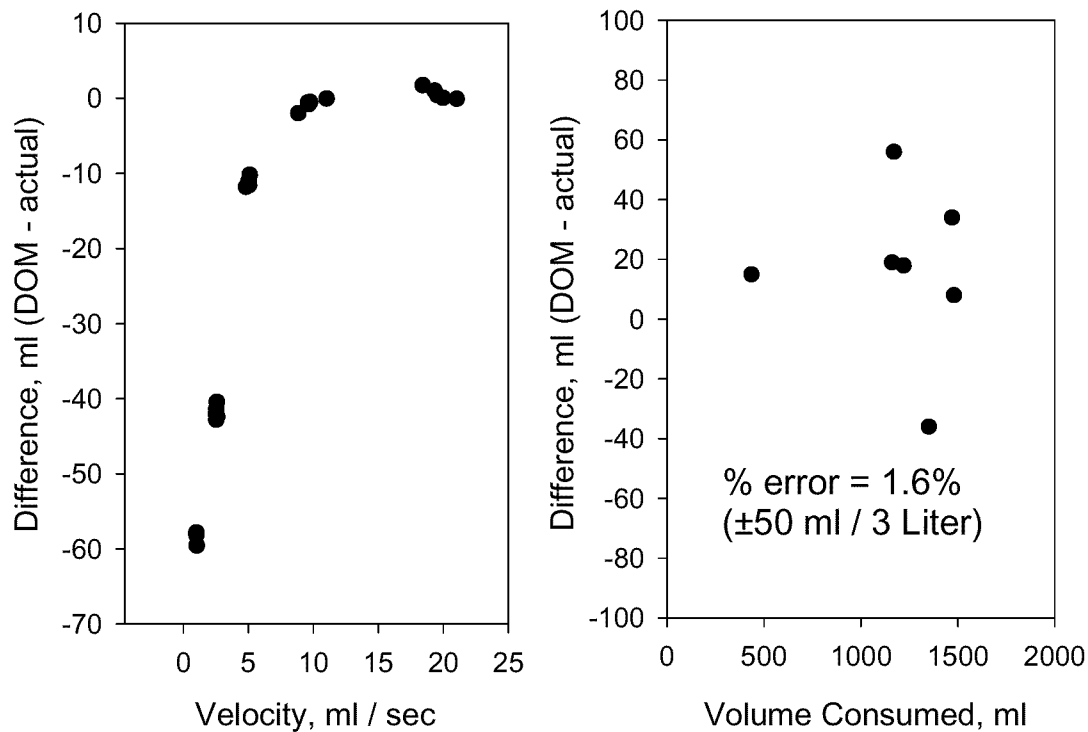


Figure 5. (Left) Accuracy of the Drink-O-Meter (DOM) system when known volumes of water were drawn through the drinking tube over a range of velocities. (Right) Accuracy of Drink-O-Meter for measuring ad libitum water consumption during work.

This system allows measurement of fluid intake in a very unobtrusive way over prolonged time periods. Figure 6 illustrates the cumulative water intake (top) and the volume consumed each minute (bottom) for a single individual performing prolonged work over a 55 hour period. The Drink-O-Meter data reveal that the soldier drank approximately 14 liters during the period with minute volumes ranging from 10 ml up to 170 ml and greatest intakes occurred during 3 time periods (0-10 h, 20-30 h, and 40-50 h). Thus, this type of system enables us to look not only at how much was consumed but when the fluid was consumed in relation to work, rest, etc. While the minute intake volumes might suggest that the soldier was drinking at very slow velocities, the plotted data are the total intake each minute and not the velocity of the individual drink. We are currently using the system to address whether actual fluid intakes match predicted fluid requirements.

Summary

The U.S. military has become sensitive that overhydration can compromise health and has acted to better sustain hydration during training. One action has been to revise fluid consumption guidelines used in training. This action appears to be having the desired effect. We are also developing new technology to study fluid intake in field environments. We foresee that this effort will help refine predictions of fluid requirements during combat situations and better sustain hydration.

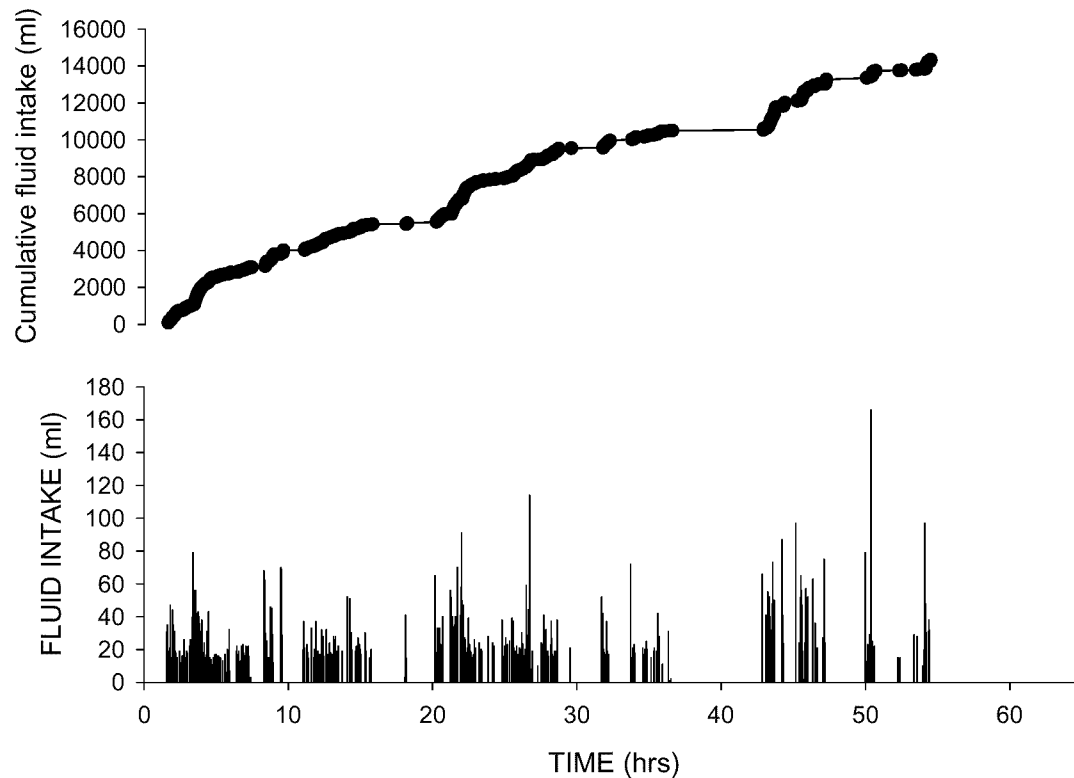


Figure 6. (Top) Cumulative water consumption of a single soldier during 55 h of sustained work. (Bottom) Fluid intake each minute of the 55 h task.

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