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Effects of water and water + electrolytes on changes in body temperature, hydration status and drinking behaviors during arduous wildfire suppression

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Introduction

Our laboratory has recently determined the total energy expenditure during wildland fire suppression activities using the doubly labeled water (DLW) and heart rate methodologies (Burks et al., 1998, Ruby et al., 2002). Although there is variation in the calculated rates of TEE (dependent on fire location, work detail, amount of hiking and fire line construction duties), values range from approximately 12.6 – 26.5 MJ.d-1 (3000 – 6300 kcals.d-1) (Ruby et al., 2002). This data demonstrates a unique work environment that requires the wildland firefighter (WLFF) to make immediate adjustments to their dietary and water intake. These workers are expected to maintain a daily arduous work rate while maintaining adequate energy intake (EI) within the dietary confines of the fire camp. Our data suggests that during arduous and extended assignments, euhydration and energy balance are challenged when total energy expenditure can increase in upwards of 3.6 times basal metabolic rate.

We have also conducted extended measures of water turnover in this population in anticipation that the hydration demands of the occupation are extreme given the length of the workshift and the heat due to the environment (ambient weather in addition to the commonplace radiant heat from the fire). The results of this hydration study demonstrate that the wildland firefighter has a tendency to lose total body mass and total body water during five days of wildfire suppression activity. The calculated rates of water turnover from 2H2O elimination indicate that the hydration demand of the job is extreme and amounts to a minimal ingestion of approximately 6-8 liters of water.d-1from beverages and other food sources. The range of rH2O was 74.0 – 136.8 ml.kg-1.d-1 (mean=94.8±20.1 ml.kg-1.d-1) in the WLFF exceeding values reported during trekking (79±17 ml.kg-1.d-1) at a moderate altitude and during mountaineering at high altitude (73±20 ml.kg-1.d-1 during ascent, 83±17 ml.kg-1.d-1 during descent) reported by Fusch et al. (1996, 1998). These values are likely a function of ambient temperature and the elevated energy expenditure previously reported in this population (Ruby et al., 2002, 2003).

The activity associated with wildland fire suppression may involve arduous hiking with a load (including a fire line pack (typically 11-16 kg), fire shelter (approximately 2 kg), and a Pulaski fire line tool (approximately 2 kg) or chainsaw (approximately 7-9 kg) and fire line construction (heavy digging or chainsaw work). The active muscle mass is diverse and the work involves a significant upper and lower body component. Therefore,glycogen depletion in a relatively large amount of muscle mass is possible when the typical work shift often exceeds 12-16 hours.d-1. The possibility of a gradual decrease and/or partial depletion of muscle glycogen has recently been discussed in conjunction with our water turnover paper (Ruby et. al, 2003).

Because the WLFF is often subjected to unpredictable field stress during wildfire suppression, this research model represents an "un-simulated" work environment involving arduous muscular work coupled with physiological and psychological stress under extreme environmental conditions (altitude and ambient heat). Moreover, our previous work (Ruby et al., 2002, 2003) was collected over five wildfire assignments (MT, CA, FL, ID, and WA) under diverse working conditions and terrain. We noted that the TEE of a 5-day wildfire suppression period was mostly dependent on the terrain and daily shift length.

Although our past research has clearly indicated a harsh working environment, which challenges energy balance and hydration status, we have been unable to collect data regarding other physiological monitoring such as alterations in core and skin body temperature across the extended workshifts. This has mainly been due to a lack of available technology, which enables unhindered yet comfortable methodologies to monitor these parameters under field conditions. With the recent developments from the Minimitter company, the measures of core and skin temperature have become practical during field operations and will minimally interfere with the duties of the job assignment.

Purpose

The purpose of the present descriptive study the effects of a water + electrolyte solution on changes in body temperature, hydration status, and drinking behaviors during arduous field operations in the wildland firefighter.

Methodology

Subjects included male (n=16) and female (n=4) wildland firefighters from various Hot Shot and District crews during the Fischer fire near Leavenworth, WA. At the time of data collection, the Fischer fire was the Nations top priority wildfire. Upon arrival at the incident subjects were selected during an informational meeting with each perspective crew. Subjects were then randomly placed in one of two groups (water – consumption of water only during the day and E + water – consumption of water with electrolyte additive).

Four subjects were enrolled in the study each day during data collection. Prior to data collection, subjects were provided written consent using a University Internal Review Board approved consent form.

At 0430 the following morning, subjects collected their first void urine sample after which a nude body weight measure was obtained. After the collection of body weight, subjects ingested a minimitter core temperature capsule and had a skin temperature sensor placed on the lateral side of the left deltoid. This skin site was selected to avoid irritation with the line gear and radio packs worn during the entire workshift. An additional surface temperature sensor was placed on the outside of the vitalsense monitor holster, which was worn on the subject's belt. Subjects were then allowed to consume the normal breakfast provided.

After breakfast, subjects were provided with a specially outfitted backpack hydration system (3L capacity Camelback). Each system was equipped with a digital flowmeter system affixed inline to allow for the measurement of drinking characteristics (drinking frequency and drinking volume). This system has been developed by the United States Army Research Institute for Environmental Medicine (USARIEM) and has been validated for accuracy (DeGroot, 2001).

Upon deployment, subjects were instructed to work their entire shift while consuming all fluid through the drinking system (water only or E+water). Additional foods were allowed ad libitum throughout the shift. Subjects were instructed on how to refill the drinking system with additional water and E+water as needed. During the workshift, subjects collected additional urine samples at approximately 1030 and 1500. A final urine sample was collected at approximately one hour post shift (post shift +1 hour). Urine samples were evaluated for specific gravity using a hand held refractometer calibrated to distilled water.

After the completion of the workshift, subjects reported to our mobile lab facility directly from the fireline for a post shift measure of nude body weight and the collection of the final urine sample (post shift +1 hour). At this time, skin sensors were removed and the vital sense data logger was downloaded along with the digital drinking system. Subjects for the next days collection were prepared as indicated above.

Data was organized and managed using Microsoft Excel. Dependent variables of interest included body weight (pre and post), drinking behavior (frequency), volume (ml/hour and total workshift intake (L)), vital sense data (mean hourly core, skin, and ambient temperature (°C)). Data were analyzed using a repeated measures ANOVA to evaluate changes across the workshift and between the water and E+water groups.

Results: Descriptive data are shown in Table 1.

	Overall	**Water**	**E + Water**
Age (years)	25.5±6.0	25.2±7.0	25.7±5.2
Body weight (kg)	79.3±13.9	80.5±16.1	78.0±12.1
Height (cm)	178.8±9.0	178.8±9.7	178.8±8.7
Wildfire experience (years)	4.9±5.6	5.4±7.0	4.5±4.2

Changes in ambient temperature are shown in Figure 1. The observed drop in ambient temperature from hours 13-15 are likely a function of the end of the workshift including vehicle transport time back to the fire camp. There were no significant differences between the water and E + water group, indicating similar ambient temperature exposure. Ambient temperature was significantly elevated from hours 4-15 compared to the initial hour of the workshift.

Table 1. Subject descriptive data. Data are expressed as mean±sd.

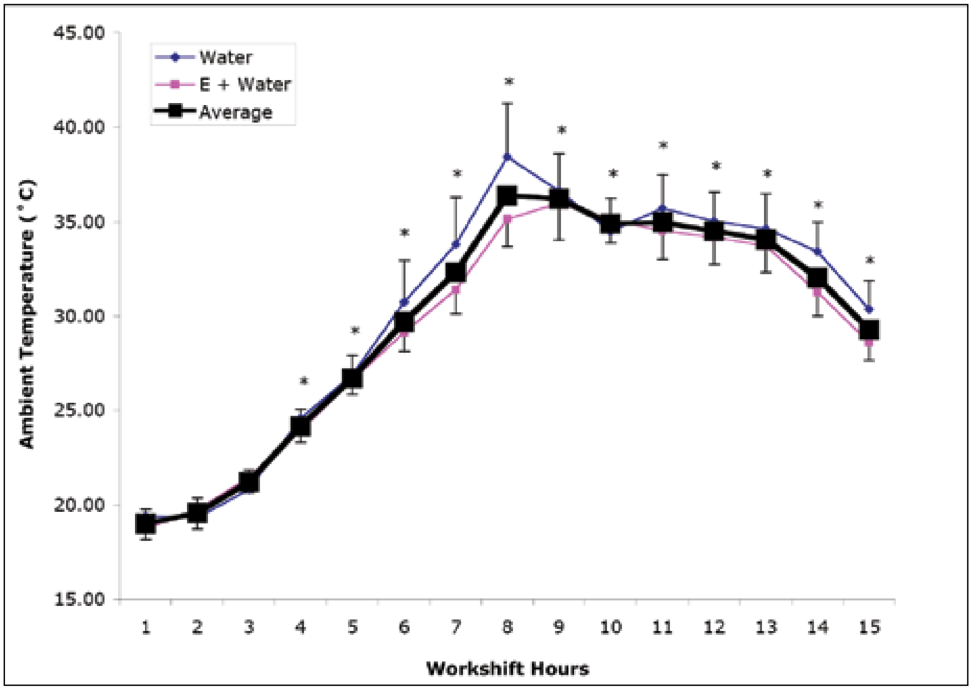

Figure 1. Changes in ambient temperature (°C) during the workshift. Values presented are average hourly computed from 60 values (1 min collection cycle) and expressed as mean±SE. * $p<0.05$ main effect for time indicating that the average values for hours 4-15 were significantly higher compared to hour 1.

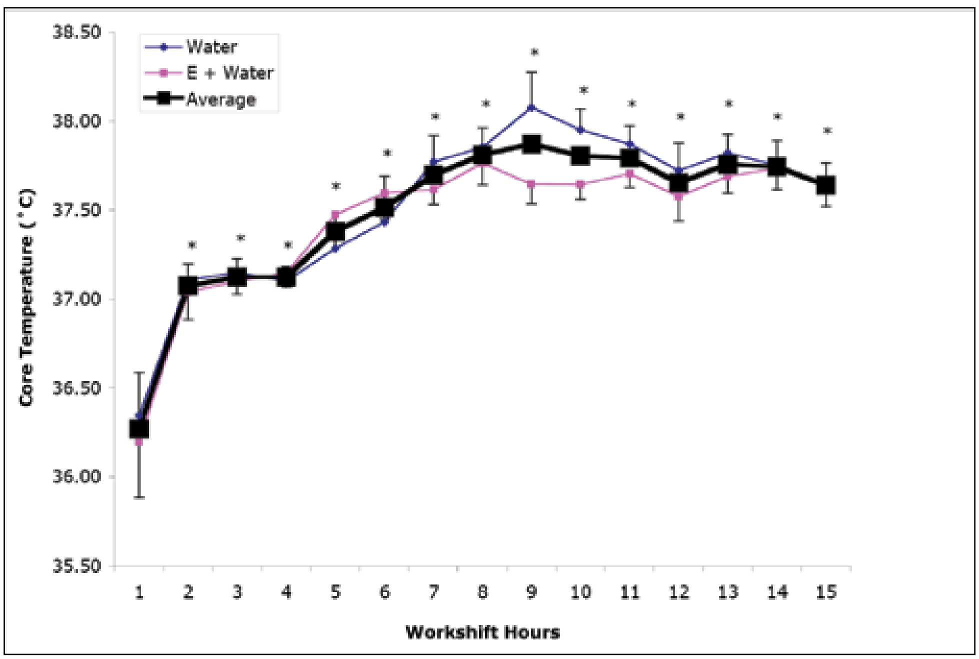

Figure 2. Changes in core temperature (°C) during the workshift. Values presented are average hourly computed from 60 values (1 min collection cycle) and expressed as mean±SE. * $p<0.05$ main effect for time indicating that the average values for hours 2-15 were significantly higher compared to hour 1.

Figure 2 shows the changes in core body temperature (°C) during the entire workshift. The main effect for time was significant, $p<0.05$. The abrupt increase in average hourly values is likely a function of transport of the sensor capsule from the stomach into the small intestine. There were no significant differences in core body temperature between the water and the E + water group.

Figure 3 shows alterations in skin temperature (°C) across the workshift, $p<0.05$ for the main effect of time. The abrupt increase in average hourly skin temperature is likely a function of the increase in ambient temperature. However, this increase can also be partially explained by the rise in core temperature. Although there were minimal differences across the water and the E + water groups, at hour 10, the E + water group demonstrated a significantly higher mean hourly values for skin temperature.

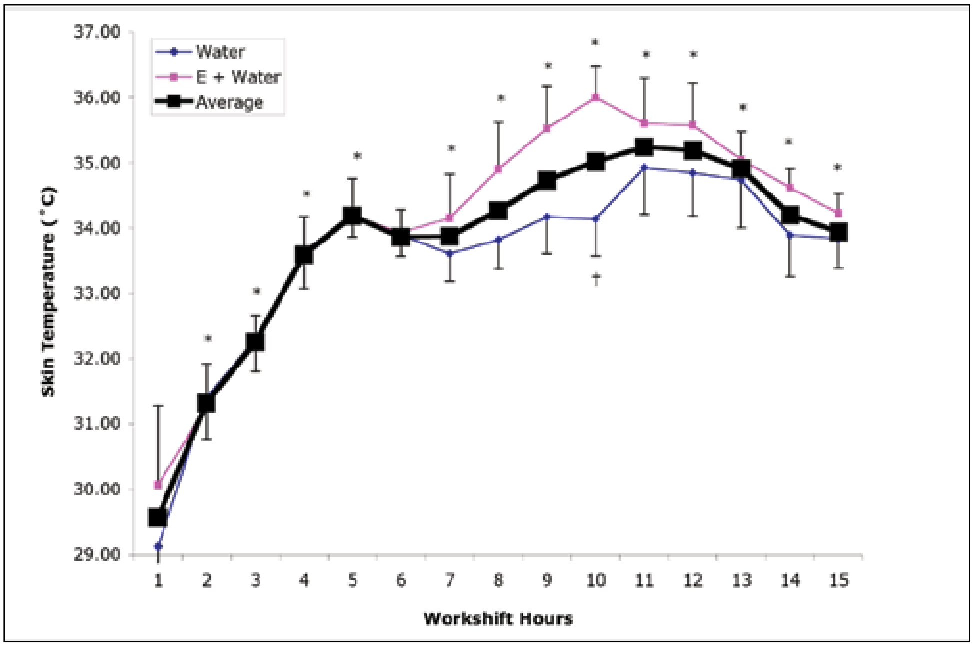

Figure 3. Changes in skin (lateral left deltoid) temperature (°C) during the workshift. Values presented are average hourly computed from 60 values (1 min collection cycle) and expressed as mean±SE. * $p<0.05$ main effect for time indicating that the average values for hours 2-15 were significantly higher compared to hour 1.

Figures 4 and 5 represent the average hourly drinking behavior. Figure 4 shows the average hourly intake pattern for the group as a whole as well as for the water and the E + water groups. Overall, there was a significant increase in hourly drinking volume from hours 6-13 vs. the second hour of the workshift. The first hour of the workshift included preparations, camp activities and crew transport, which did not include fluid intake from the hydration system. There was also a significant difference between the groups at hours 6, 7, 8, and 10 during the extended workshift demonstrating that the E + water group averaged less water intake during these hours of high wildfire suppression activity (Figure 6).

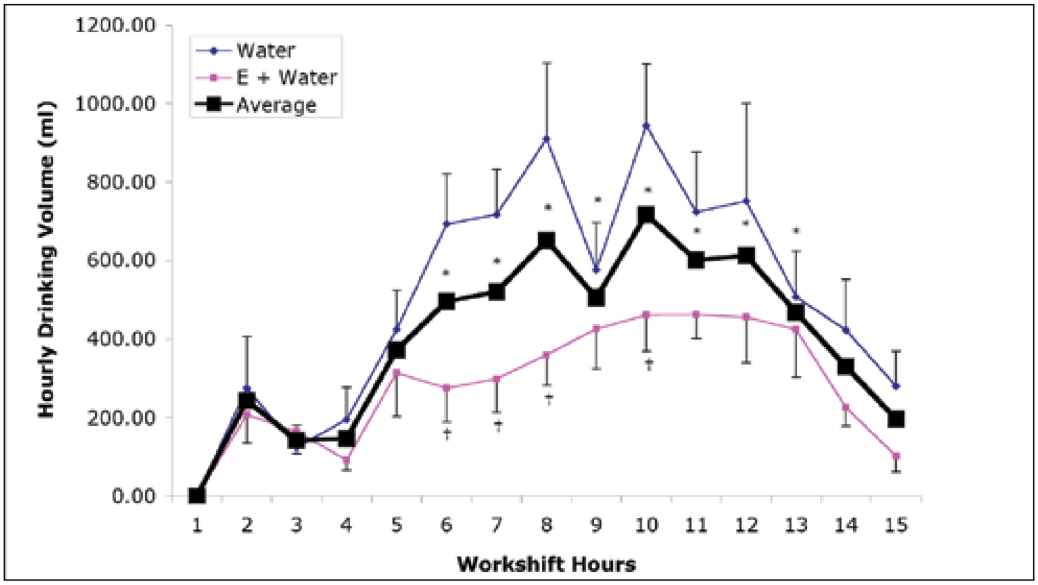

Figure 4. Changes in hourly drinking volume (ml) during the workshift. Values presented represent total hourly consumption (ml) computed from the digital drinking system and expressed as mean±SE. * $p<0.05$ main effect for time indicating that the average values for hours 6-13 were significantly higher compared to hour 1, whereas hours 2-5 and 14-15 were not significantly different from hour 1.

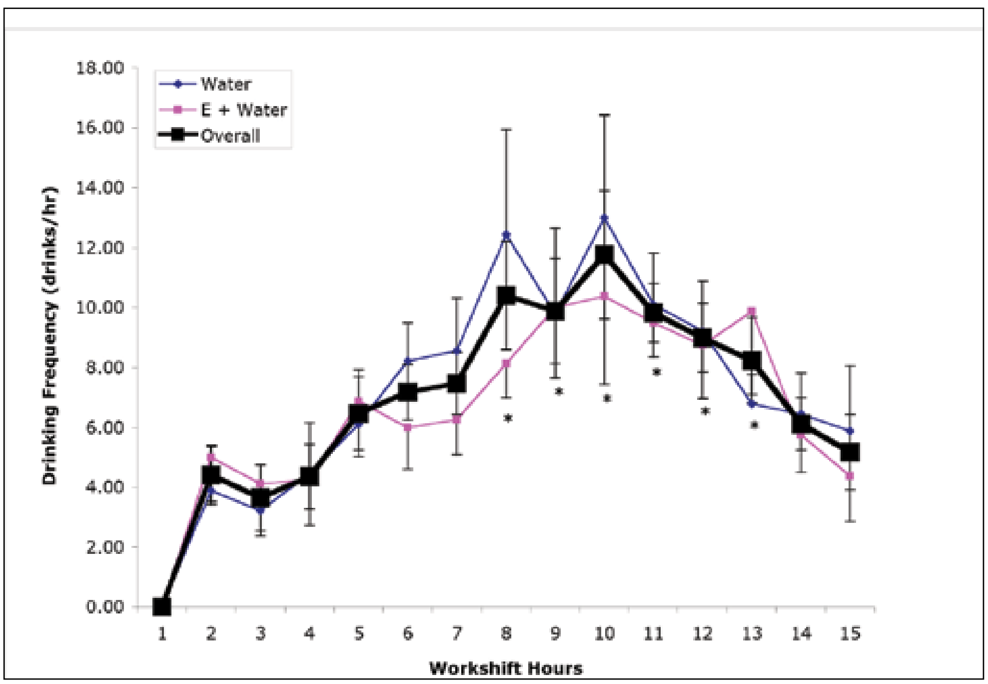

Figure 5. Changes in drinking frequency (drinks/hour) during the workshift. Values presented represent the number of drinks taken each hour computed from the digital drinking system and expressed as mean±SE. * $p<0.05$ main effect for time indicating that the average values for hours 6-13 were significantly higher compared to hour 2.

Figure 5 shows the patterns of drinking frequency. These data demonstrate an increase in the total number of drinks taken during each hour of the workshift. Although there were no differences across the water and the E + water groups, the overall data demonstrates a significant increase in drinking frequency during hours 8-13.

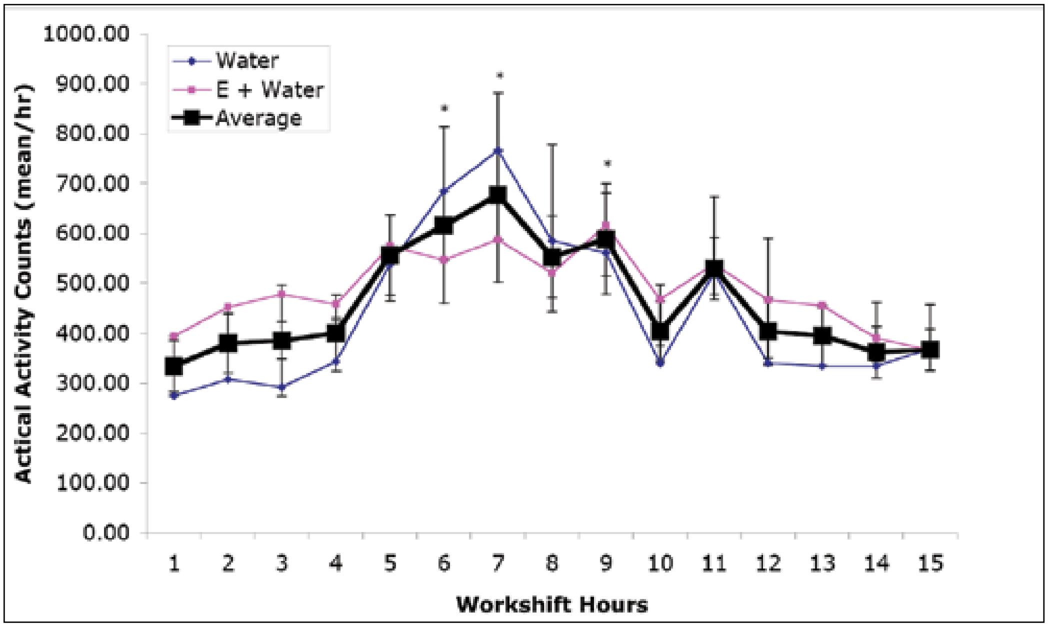

Figure 6. Variations in activity monitor counts (average hourly counts) during the workshift. * p<0.05 main effect for time indicating that the average values for hours 6-13 were significantly higher compared to hour 2.

The overall change in nude body weight demonstrated a significant (p<0.05) decrease across the workshift (79.8 and 79.1 kg for pre and post shift values, respectively.) for the entire group (N=20). There were no differences between the two groups (Pre=79.8±16.6, Post=79.4±16.3 kg and Pre=78.0±12.1, Post=77.1±12.5 kg for the water and water +E groups, respectively).

Total drinking volume averaged 6.0±2.6 L for the entire group. There was a significant difference (p<0.05) in total workshift drinking volume across the water (7.5±2.3 L) and E + water (4.3±1.8 L) groups. This significant difference indicates that the E + water group consumed a total of 3.2 L or 3.2 kg less than the water group.

Conclusions: These data demonstrate alterations in ad libitum drinking behavior that parallel select physiological and environmental measures. That is, drinking frequency and volume appear related to ambient, skin, and core temperature. Interestingly, the values for total fluid intake during the workshift are slightly lower than rates of water turnover previously reported by our laboratory for this population (6.7 L/day). However, if fluid intake from breakfast and post shift dinner are included, total estimated fluid intake approximates our previous measures of water turnover.

The major findings from this study are summarized below.

- Wildland firefighters in the water and E + water groups were exposed to similar ambient temperatures and demonstrated similar responses in core body temperature.

- Skin temperature was similar between the water and the E + water groups except for hour 10, which demonstrated a significantly higher value for the E + water group.

- Although there were no differences in drinking frequency across the groups, The water group consumed a significantly higher amount during hours 6, 7, 8, and 10 compared to the E + water group.

- The total water intake was 3.2 L less for the E + water group.

- There were no differences in self-selected work rates between the water and E + water groups.

- The minimitter physiological monitoring system represents a robust data collection device that is built to withstand the rigors of most field environments. Moreover, the vitalsense monitor greatly expands the capabilities for arduous field data collection under extreme environmental conditions.

In conclusion, these data demonstrate the effectiveness of electrolyte additives to normal drinking water under arduous working conditions. As indicated above, the weight loss was similar for both groups (water=-0.36kg, E + water=-0.96 kg). This difference amounts to 0.6 L or 0.6 kg. In contrast to the minimal difference noted in weight loss between the groups, the total drinking volume was 3.2 L higher for the water only group. This indicates that the water only group was required to consume more total water throughout the day in an attempt to maintain body weight and whole body hydration. This is especially important to consider as the rate of self-selected work was similar between the two groups.

Under arduous field conditions, water availability can become an issue because of the logistics associated with transport and cleaning. These current data indicate that when water is treated with small amounts of supplemental electrolytes, less is required to maintain whole body hydration. Subjects did comment that the taste of the E + water was less desirable. However, the water only group also commented on the warmth of the water due to the use of the camelback hydration systems. Numerous subjects commented that they felt the taste downregulated their intake patterns. Regardless, less total water intake was required to attain the same 'end of shift" hydration status as indicated by the measure of nude body weight.

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