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ORIGINAL RESEARCH

Effects of an Electrolyte Additive on Hydration and Drinking Behavior During Wildfire Suppression

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Objective.—The purpose of this study was to compare the effects of a water + electrolyte solution versus plain water on changes in drinking behaviors, hydration status, and body temperatures during wildfire suppression.

Methods.—Eight participants consumed plain water, and eight participants consumed water plus an electrolyte additive during 15 hours of wildfire suppression. Participants wore a specially outfitted backpack hydration system equipped with a digital flow meter system affixed inline to measure drinking characteristics (drinking frequency and volume). Body weight and urine-specific gravity were collected pre- and postshift. Ambient, core, and skin temperatures were measured continuously using a wireless system. Work output was monitored using accelerometry.

Results.—There were no differences between groups for body weight, drinking frequency, temperature data, activity, or urine-specific gravity (1.019 $\pm$ 0.007 to 1.023 $\pm$ 0.010 vs. 1.019 $\pm$ 0.005 to 1.024 $\pm$ 0.009 for water and water + electrolyte groups pre- and postshift, respectively; $P < .05$). There was a main effect for time for body weight, demonstrating an overall decrease (78.1 $\pm$ 13.3 and 77.3 $\pm$ 13.3 kg pre- and postshift, respectively; $P < .05$) across the work shift. The water group consumed more total fluid (main effect for treatment) than the water + electrolyte group (504 $\pm$ 472 vs. 285 $\pm$ 279 $mL \cdot h^{-1}$ for the water and water + electrolyte groups, respectively; $P < .05$).

Conclusion.—The addition of an electrolyte mixture to plain water decreased the overall fluid consumption of the water + electrolyte group by 220 $mL \cdot h^{-1}$ (3.3 $L \cdot d^{-1}$). Supplementing water with electrolytes can reduce the amount of fluid necessary to consume and transport during extended activity. This can minimize carrying excessive weight, possibly reducing fatigue during extended exercise.

Key words: firefighting, ultraendurance, water, electrolyte solution, hydration

Introduction

In the Northwest United States during the summer months, wildland fire suppression occurs wherever fires threaten human structures, power areas, towns, or cities. The job of the wildland firefighter (WLFF) involves laborious work during 14-day deployments, composed of 12- to 16-hour days doing activities such as hiking, digging lines, chain sawing, and managing controlled burns.[1–3] Wildland firefighters typically work in environments with high ambient heat ($\geq$40°C), low humidity, and rugged terrain. They carry a 12- to 20-kg pack containing food, water, safety gear, and work tools. A considerable amount of weight in the pack (upwards of ~50%) consists of fluids used for personal hydration. To obtain maximal safety and work output, it is critical for the WLFF to eliminate carrying any excessive weight during the workday, which may help reduce fatigue.

Using the doubly labeled water methodology, we have previously reported the energy demands of wildfire suppression (12–26 $MJ \cdot d^{-1}$, 2868–6214 $kCal \cdot d^{-1}$).[3] We have also reported rates of water turnover during wildland fire suppression (6.7 $\pm$ 1.4 $L \cdot d^{-1}$, 94.8 $\pm$ 24.1 $mL \cdot kg^{-1} \cdot d^{-1}$), and WLFFs have been shown to lose approximately 1 kg of body weight following 5 days of work.[2] This drop in body weight was accounted for by

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Table 1. Descriptive data*

	Water (n = 8)	*Water + electrolyte* (n = 8)	*Overall*
Age (years)	23.0 ± 2.4	25.6 ± 5.4	24.3 ± 4.3
Height (cm)	179.7 ± 10.8	176.8 ± 8.5	178.3 ± 9.5
Weight (kg)	79.8 ± 16.6	76.3 ± 10.0	78.1 ± 13.3

*Values are mean ± standard deviation.

a decrease of 0.9 kg total body water with minimal changes in urine osmolality and specific gravity.

While wildfire suppression is not a sport, the physiologic stresses mentioned above mirror the metabolic demands of ultraendurance athletes. The only difference is the work:rest cycle is about 1:2 for wildfire suppression,[1] whereas many ultraendurance sports would be more continuous (ie, Ironman triathlons and ultrarunning). Appropriate fluid balance is critical before, during, and after exercise in order for athletes, as well as WLFFs, to perform optimally.[4–7] Hydration during exercise events is important not only to maximize performance, but to avoid deleterious health problems, such as heat exhaustion, hyponatremia, acute renal failure, or rhabdomyolysis.[7–9] Maintaining euhydration is important for athletes and WLFFs, but fluid balance can be maintained even when individuals lose weight. When athletes exhibit weight loss during extended exercise but remain in fluid balance, it has been suggested that the weight loss is a consequence of fat and glycogen loss, as well as the intracellular water stored with glycogen.[2,10,11]

Considerable research has investigated the effects of sodium and/or other electrolytes added to drinks to improve hydration status during exercise and to restore hydration more quickly following an exercise bout.[12,13] There is evidence during ad-libitum fluid intake situations that flavored drinks are more efficacious for fluid balance than plain water.[14–16] During extended exercise, sodium supplementation has been shown to decrease weight loss compared to placebo[17] and reduce dehydration.[18] However, there appears to be no performance benefit to sodium supplementation during extended exercise.[17,19,20] During rehydration, consumption of fluids containing electrolytes typically decreases urine output,[21–23] better restoring fluid balance postexercise. However, Mitchell et al[24] showed no differences in urine volume when large quantities of fluid were consumed with or without sodium.

Although past research on WLFFs has clearly indicated a demanding work environment that challenges energy balance and hydration status, data regarding drinking patterns and its effect on hydration status and thermoregulatory stress have not been collected. This has been limited by a lack of available technology that allows unhindered work efforts by the participants and comfortable equipment to monitor these parameters under field conditions. The purpose of this study was to compare the effects of a water + electrolyte solution versus plain water on changes in drinking behaviors, hydration status, and body temperatures during wildfire suppression. It was hypothesized that there would be minimal differences between those consuming the water + electrolyte solution versus water due to the small amounts of electrolytes added.

Methods

PARTICIPANTS

Participants included male (n = 12) and female (n = 4) type II professional WLFFs working at a fire in the Northwestern United States (for descriptive data, see Table 1). Upon arrival at the incident, participants were recruited during an informational meeting. Four participants completed the study each day; 2 participants received water and two received water + electrolyte in a double-blind fashion. All WLFFs wore standard fire equipment: Nomex long-sleeve shirt and pants, midcalf leather logger boots, a 100% cotton short-sleeve undershirt, leather gloves, hard hat, and a 12- to 20-kg pack containing food, water, safety gear, and work tools.[3] The study was approved by the University of Montana Institutional Review Board, and participants provided written consent prior to data collection.

EXPERIMENTAL DESIGN

Participants were randomly placed in one of 2 groups: water (consumption of water only) and water + electrolyte (consumption of water with electrolyte additive). The electrolyte additive consisted of a commercially available product (*Elete* by Mineral Resources, Ogden, UT). Each L of water + electrolyte contained 22.8 $mmol \cdot L^{-1}$ of electrolytes (45 mg magnesium, 125 mg

Table 2. Markers of hydration during 15 hours of wildfire suppression*

	Water (n = 8)	*Water + electrolyte* (n = 8)	*Overall* (n = 16)
Preshift BW (kg)	79.8 ± 16.6	76.3 ± 10.0	78.1 ± 13.3
Postshift BW (kg)	79.4 ± 16.3	75.3 ± 10.3	77.3 ± 13.3†
Preurine SG	1.019 ± 0.007	1.019 ± 0.005	1.019 ± 0.005
Posturine SG	1.023 ± 0.010	1.024 ± 0.009	1.023 ± 0.009†

*Values are mean ± standard deviation. BW indicates body weight; SG, specific gravity.
†$P < .05$ from pre- to posturine, main effect for time.

sodium, 390 mg chloride, 130 mg potassium, and 20 mg sulfate).

Following the collection of morning nude body weight and first void urine sample, participants ingested a core temperature capsule (Jonah capsule, Mini Mitter a Respironics Company, Bend, OR) and had a skin temperature sensor (Mini Mitter) 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 work shift. An additional surface temperature sensor was placed on the outside of the VitalSense monitor holster (Mini Mitter), which was worn on the firefigher's belt. Participants were then allowed to consume the standard catered breakfast provided, which consisted of unlimited portions of food and drink.

After breakfast, participants were provided with a specially outfitted backpack hydration system (3-L capacity CamelBak, Petaluma, CA). Each system was equipped with a digital flow-meter system affixed inline to allow for the measurement of drinking characteristics (drinking frequency and drinking volume). This system has been validated for accuracy and reliability.[25]

Activity data were collected using the ActiCal actigraphy units (Mini Mitter) via methods previously described.[1] Briefly, activity monitors were initialized to collect data at the beginning of the shift, placed on a white foam square (~7.6 cm × 7.6 cm), and inserted in the left shirt pocket of participants. These monitors detect movement in an omnidirectional fashion, ideal for sensing upper body movements frequently performed by WLFFs.

Upon deployment, participants were instructed to work their entire shift while consuming all fluid through the drinking system. Participants were instructed to drink as much or as little fluid as they desired during the work shift. Solid food consumption was ad libitum, consisting of a sack lunch containing ~6.3 to 8.4 MJ (~1506 to 2008 kCal) if completely consumed, and other supplementary foods, such as miscellaneous food bars and seasoned dried meat.[1] While in the field, participants refilled their drinking system as needed by pouring 3 L of water into the Camelback and adding a small vial of either placebo or electrolyte mix. The refilling procedure should not have unblinded participants to the drink, unless they tasted the contents of the vial before pouring it into the Camelback.

After the completion of the work shift, nude body weight was measured and urine samples were evaluated for specific gravity using a hand held refractometer (Atago Uricon-NE, Farmingdale, NY) calibrated to distilled water. At this time, skin sensors were removed and the VitalSense data logger, digital drinking system, and activity monitors were downloaded.

STATISTICAL ANALYSIS

Data were analyzed using a mixed-design analysis of variance (trial × time) with repeated measures to evaluate changes across the work shift and between the water and water + electrolyte groups. Statistical significance was established using an α level of $P < .05$.

Results

BODY WEIGHT

There was a main effect for time for the overall decrease in nude body weight across the work shift ($P < .05$) (Table 2). There was no statistically significant difference between the water and water + electrolyte groups.

DRINKING BEHAVIOR

The water group consumed more total fluid throughout the whole day than the water + electrolyte group (504 ± 472 vs. 285 ± 279 $mL \cdot h^{-1}$ for the water and water + electrolyte groups, respectively; $P < .05$). Drinking volume was higher (main effect for time) during hours 6 to 13 compared to hour 2; $P < .05$ (Figure 1). Drinking data for the first hour were not analyzed, since dur-

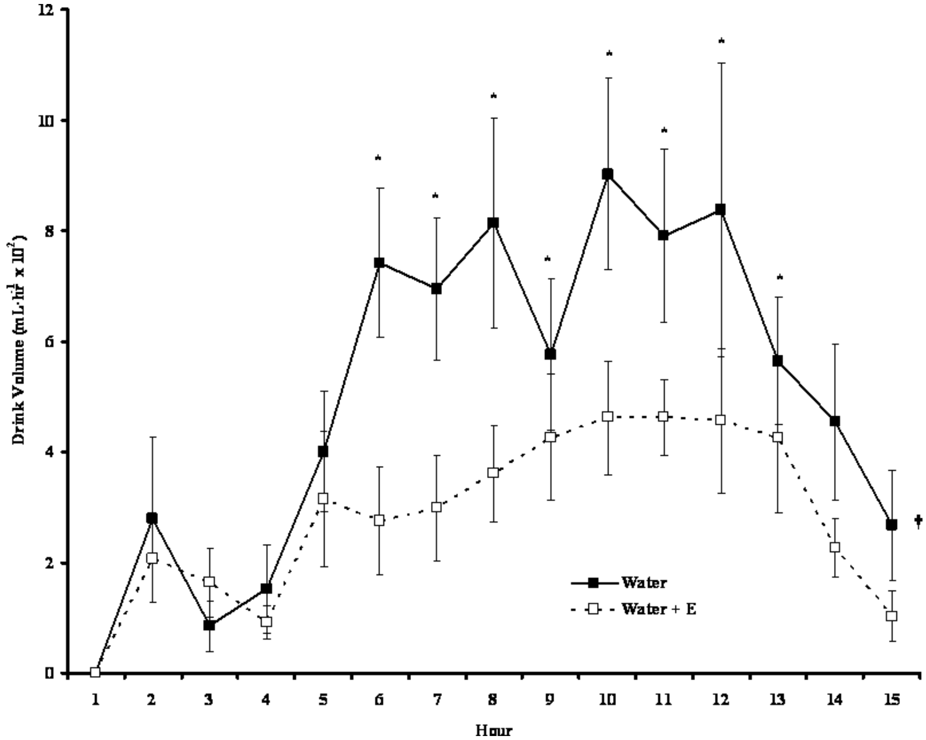

Figure 1. Drinking volume during 15 hours of wildfire suppression. **P* < .05 compared to hour 2, main effect for time. †*P* < .05 main effect for treatment. E = electrolyte additive.

ing this hour crews were in camp and did not consume fluid from the hydration system.

There was no difference between groups for number of drinks throughout the day (93 ± 28 and 99 ± 32 drinks$\cdot d^{-1}$ for the water and water + electrolyte groups, respectively; Figure 2). There was a main effect for time indicating more drinks$\cdot h^{-1}$ during hours 8 to 13 than during hour 2.

TEMPERATURE

There were no significant differences in ambient, core, or skin temperature between the water and the water + electrolyte group (Figure 3). Ambient temperature was significantly ($P < .05$) elevated from hours 4 to 15 compared to hour 1. Core body temperature was significantly ($P < .05$) elevated from hours 2 to 15 compared to hour 1. Skin temperature was significantly ($P < .05$) elevated from hours 3 to 15 compared to hour 1.

ACTIVITY

There was no difference between the water and water + electrolyte groups in average self-selected work output over the entire workday (426 ± 328 and 483 ± 311 counts$\cdot min^{-1} \cdot h^{-1}$, for the water and water + electrolyte groups, respectively; Figure 4). There was a significant main effect for time, with work output during hours 5 to 9 and 11 higher compared to hour 1.

URINE-SPECIFIC GRAVITY

There was a significant increase in urine-specific gravity from preshift to postshift ($P < .05$) (Table 2). However, there was no difference between the water and water + electrolyte groups.

Discussion

The primary finding from the current study is that when an electrolyte supplement was added to plain water, individuals consumed significantly less fluid overall (220 $mL \cdot h^{-1}$, or 3.3 $L \cdot d^{-1}$) during 15 hours of wildland fire suppression yet exhibited similar thermoregulatory stress responses and body weight change. Participants in both groups sustained similar decrements in body weight (−0.5% ± 0.9 and −1.4% ± 1.3 for the water and water + electrolyte groups, respectively) and changes in urine-specific gravity despite the water + electrolyte group consuming 43% less fluid (7.6 ± 2.4 vs. 4.3 ± 1.8 $L \cdot d^{-1}$ for the water and water + electrolyte groups, respectively) over the 15-hour work shift. Reducing the

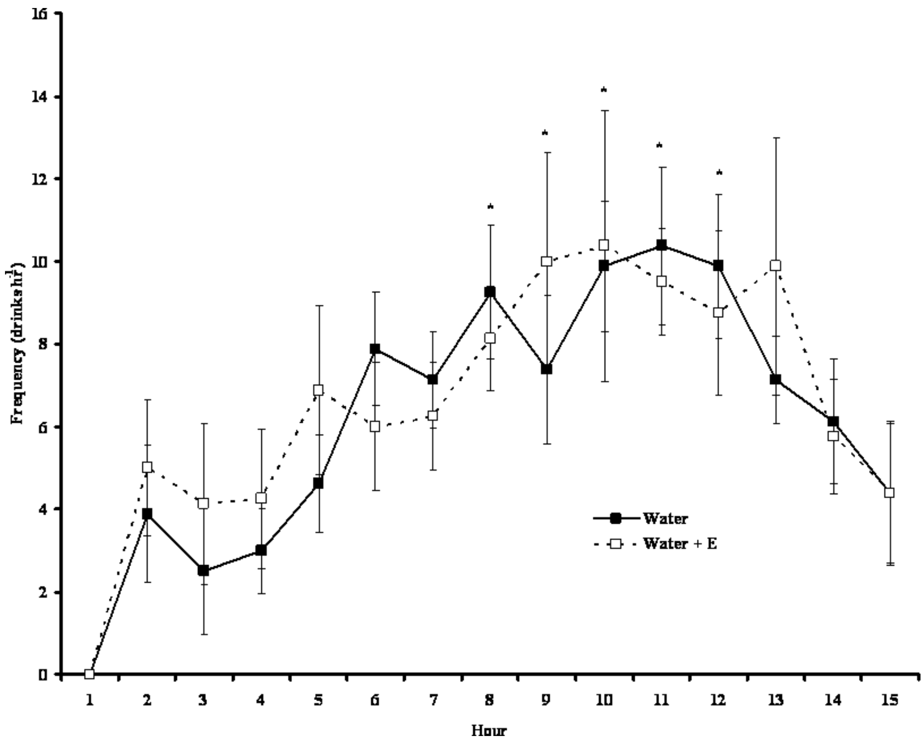

Figure 2. Drinking frequency during 15 hours of wildfire suppression. *$P < .05$ compared to hour 2, main effect for time. E = electrolyte additive.

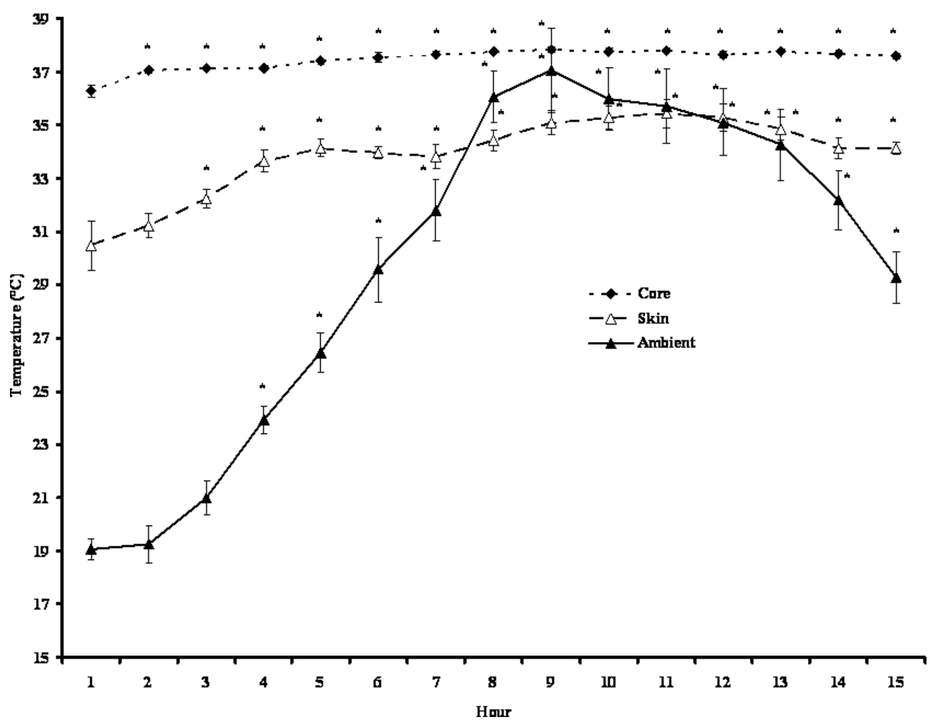

Figure 3. Core, skin, and ambient temperatures during 15 hours of wildfire suppression. *$P < .05$ compared to hour 1, main effect for time.

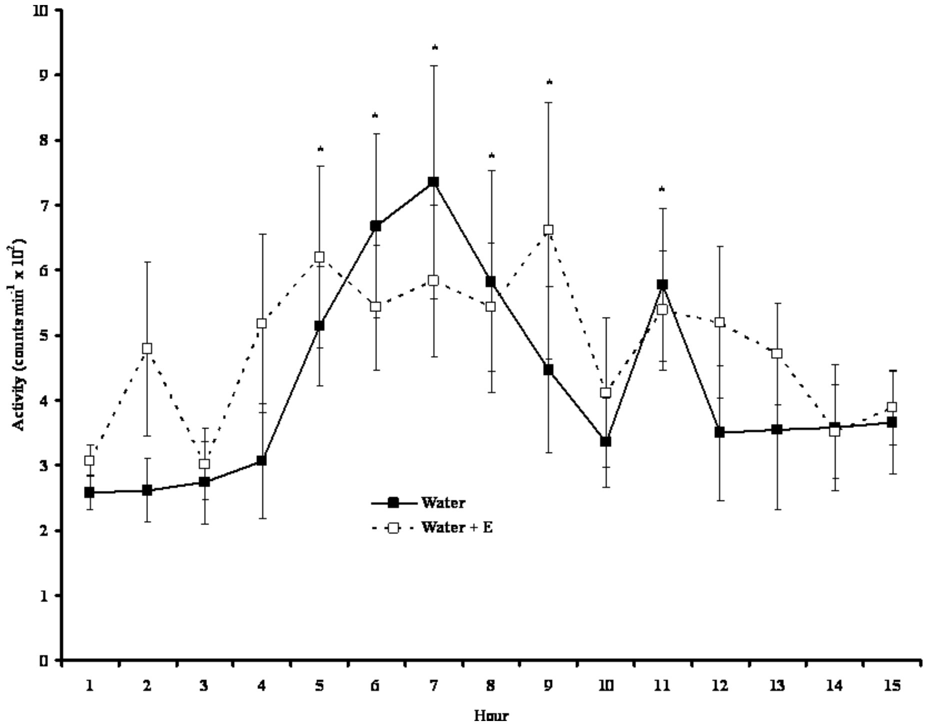

Figure 4. Self-selected work activity during 15 hours of wildfire suppression. *$P < .05$ compared to hour 1, main effect for time. E = electrolyte additive.

need for fluid by 43% demonstrated in the water + electrolyte group would allow time to be more effectively spent in direct wildfire suppression activities. However, there were no differences in self-selected work output patterns between the groups. Without any fluid intake suggestions, recommendations, or guidelines, WLFFs in both groups were able to self-select a sufficient amount of fluid to maintain similar levels of hydration while engaged in difficult working conditions.

The hourly drinking volume for the water group (504 $\pm$ 472 $mL \cdot h^{-1}$) is similar compared to reported literature,[4,7,11,26] while the water + electrolyte group consumed less (285 $\pm$ 279 $mL \cdot h^{-1}$) than typically reported. Even though the intensity at which WLFFs work is considerably less than ultraendurance exercise events,[1] the work shift duration is similar to or longer than such sporting events. During wildland fire suppression efforts in the Australian bush, Hendrie et al[26] showed that firefighters consumed 331 $mL \cdot h^{-1}$, dehydrating at a rate of 0.9% body mass per hour, even when water and time to drink it was readily available. Participants in the Hendrie study consistently drank too little, demonstrating a pattern called "voluntary dehydration," first recognized by Adolph in 1947 while researching soldiers in the desert.[27] Typical fluid intakes for ultraendurance exercise have been reported between ~300 to 1300 $mL \cdot h^{-1}$ [(4)], with intakes during Ironman triathlons reported at 716 $mL \cdot h^{-1}$, [(11)] and 1.5 $L \cdot h^{-1}$.[28] For WLFFs, military combatants, mountain climbers, backpackers, and others for whom water sources may be scarce, the current data suggest that adding additional electrolytes to fluid mixtures might reduce the amount of fluids that need to be consumed, thus reducing the amount that might have to be transported subsequently reducing load carriage and the energy demands associated with load carriage. Future research should explore whether using supplemental electrolytes over a longer duration study (~14 days) would reduce the amount of fluid necessary to maintain hydration.

In the current study, environmental conditions during the work shift followed typical trends for the Northwest United States during the month of August: hot and dry, with low humidity. Temperatures hovered between 29°C and 38°C during hours 6 to 13 of the work shift, and it was common for some participants to experience ambient temperatures exceeding 40°C, with 1 subject experiencing 1 average hourly ambient temperature of 46.8°C. Participants consumed a significantly higher volume of fluid during hours 6 to 13, paralleling the increase in ambient temperatures and activity (Figures 1, 3, and 4). During hours 6 to 13 (mean ambient temperature 34.4 $\pm$ 4.6°C), participants consumed a mean volume of 568 $\pm$ 422 $mL \cdot h^{-1}$, consistent with reported voluntary fluid intakes during various sports.[7] Additionally, participants took more frequent drinks as the work shift progressed and temperature increased, particularly during hours 6 to 13 (Figure 2). The increases in drinking volume and frequency parallel the increases in ambient temperature and activity, suggesting that increasingly stressful environmental conditions coupled with consistent work activity increase the need/desire for increased fluid intake (Figures 2, 3, and 4).

Despite the large difference in overall drinking volume between groups, WLFFs in the current study demonstrated similar drinking frequency patterns. Participants drank a comparable number of times during the day, 93 ± 28 and 99 ± 32 for the water and water + electrolyte groups, respectively. Speedy et al[17] suggested that sodium ingestion during exercise could have an effect on thirst, causing athletes to consume more fluid during an Ironman race compared to athletes not supplementing with sodium. Other studies where ad libitum drinking was permitted have shown flavored drinks enhance fluid balance[14–16]; however, in studies where fluid intake was provided to match sweat rate, there was no benefit to consuming drinks with saline or carbohydrate + electrolyte.[29,30]

It has been previously demonstrated that sodium supplementation reduces urine output and expands plasma volume, thus hastening rehydration.[21,23] The water + electrolyte group may have had a reduced urine production due to the addition of electrolytes to their drink, thus minimizing the need to consume more fluid, while the water group drank more but had a higher urine production. This is a definite possibility in the current study, since it has been suggested sodium intake activates hormonal control mechanisms and reduces the excretion of water.[23] Urine output data were not collected, so this is speculation. However, slight changes in urine production during the day, especially a 15-hour work shift, would accumulate over a long duration.

It is difficult to accurately ascertain the hydration status of WLFFs in the current study, since study participants were several days into their 14-day deployment, and no baseline data were collected prior to its beginning. Nonetheless, the primary 2 markers we collected to monitor hydration, body weight and specific gravity, indicated no difference between groups. The weight loss was slightly greater (though not significant) for the water + electrolyte group, both as an absolute and a percentage of body weight. For both groups, the mean decrease in weight from pre- to postshift was $1.0 \pm 1.2\%$ of body weight, while specific gravity increased from $1.019 \pm 0.005\ g \cdot mL^{-1}$ to $1.023 \pm 0.009\ g \cdot mL^{-1}$ from pre- to postshift. The small weight loss the WLFFs experienced was within the accepted euhydration cut-off ($<2\%$) as outlined by the recent position stand by the American College of Sports Medicine.[7] However, the post measure of specific gravity was slightly greater than the euhydration cut-off ($<1.020\ g \cdot mL^{-1}$) recommended in the same position stand. Technically, these 2 variables would suggest our participants began the day euhydrated and finished the day slightly dehydrated. However, prior to the beginning of the work shift the urine-specific gravity was close ($0.001\ g \cdot mL^{-1}$) to the euhydration cut-off point and then changed minimally ($0.004\ g \cdot mL^{-1}$) during 15 hours of wildland fire suppression. It is possible that WLFFs consistently fluctuate between the point of euhydration and dehydration during the day. Given the high energy expenditure[3] and rates of water turnover[2] during wildland fire suppression, the self-selected fluid intake created minimal disturbance in the hydration status of the current participants (ie, weight loss was minimal and urine-specific gravity changed little). Whether the slight weight loss observed during this study came from sweat or substrate utilization, as has been previously suggested,[2] remains unknown. Accurately calculating sweat rate in this environment would have been a formidable task, and because of individual variability in sweat rates, a general assumption cannot be made. Further research may be warranted to evaluate substrate utilization or glycogen loss during wildland fire suppression.

Some WLFFs commented the water + electrolyte was less desirable than plain water, even though the amount of electrolytes in the water + electrolyte drink was 22.8 $mmol \cdot L^{-1}$, considerably below the levels that might decrease palatability, as suggested by Barr et al.[29] Barr et al[29] have suggested that high levels of electrolytes (43–87 $mmol \cdot L^{-1}$) added to water would decrease the palatability of drinks, while Speedy[17] has suggested that increased sodium in water would increase the desire to drink (thus athletes would consume more water). Even if there was a decrease in the palatability of the water + electrolyte drink resulting in reduced intake compared to water, both groups maintained similar decrements in body weight and increases in urine-specific gravity. In addition, there were no differences in core or skin temperatures, suggesting similar thermoregulatory stress responses.

While all attempts were made to control extraneous factors that might influence results in this study, there are several limitations. First, the palatability of the electrolyte solution could have discouraged subjects from consuming copious amounts of fluid, but many participants remarked their drinks tasted normal. However, there was no effort to equalize taste between the water and water + electrolyte drinks, and no formal attempt was made to assess the palatability of the electrolyte mix. Oftentimes CamelBak packs incur a "plastic" taste to water, and perhaps this masked any taste differences of the electrolyte solution. Next, there is the possibility that WLFFs consumed water from other sources throughout the day. They had access to plain water and possibly sports drinks, but were instructed to only drink from their Camelback. From many years of research with the WLFFs, our laboratory has found them to be cooperative, diligent, and honest with their efforts. Further, it is possible that urine-specific gravity and body weight measures were too crude to detect hydration changes, or normal physiologic hydration reserves and compensatory mechanisms minimized any differences. Finally, researchers collected no dietary information regarding the frequency or amount of snacks and foods consumed during the work shift. Food intake could have impacted body weight changes, especially if subjects in the electrolyte group chose to eat more. If that were the case, differences in body weight resulting from dissimilar drinking patterns would have been minimized. However, participants were provided similar sack lunches to consume during the day, so food intake was most likely consistent between groups.

In summary, the addition of an electrolyte mixture to plain water was associated with a decrease in overall fluid consumption of the water + electrolyte group by 220 $mL \cdot h^{-1}$, or 3.3 $L \cdot d^{-1}$. Participants exhibited minimal changes in hydration status during 15 hours of arduous work by adequately self-selecting fluid intake under demanding environmental and work conditions. Having to transport and consume less fluid during the extended physical activity can minimize carrying excessive weight, possibly reducing fatigue during extended exercise.

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