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FACTORS EFFECTING CORE TEMPERATURE AND HYDRATION DURING
ARDUOUS WORK

by

Julie A. Ham

B.S. University of Montana, 2003

Presented in partial fulfillment of the requirements

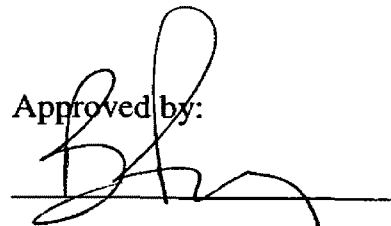
For the degree of

Master of Science

The University of Montana

May 2006

Approved by:



Chairperson



Dean, Graduate School

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FACTORS EFFECTING CORE TEMPERATURE AND HYDRATION DURING ARDUOUS WORK

Chairperson: Brent C. Ruby



Wildland firefighters (WLFF) work long shifts in extreme environmental conditions. Temperature regulation and hydration status are important factors that effect WLFF's cognitive and physical performance. Purpose: The purpose of this investigation was to determine the effects of wildfire suppression on temperature regulation and drinking behaviors during an arduous day on the fireline. Methodology: Subjects included male (n=16) and female (n=4) wild land firefighters from various Hot Shot and District crews. Core, skin, and ambient temperature and self-selected work rate (via activity monitor) were measured using a wireless physiological monitoring system. Drinking characteristics were recorded with a previously validated flow meter, which allowed for the measures drink volume/rate (ml/hr), drink frequency (drinks/hour), and total volume (L/workshift). Urine specific gravity was measured at 2nd AM void, late AM, late afternoon, and post shift + 1hr. Data were analyzed across the day by comparing average AM and PM workshift values with repeated measures ANOVA. Results: Ambient temperature demonstrated a significant increase throughout the day (AM=24.8±2.2 and PM=34.0± 3.4°C, p<.05). There was also a significant increase in core (AM=37.2±0.3 and PM=37.8±0.02°C, p<.05) and skin (AM=32.7±1.2 and PM=34.67±1.3°C, p<.05) temperatures throughout the day. Drinking volume (ml/hour) was significantly higher during hours 8-15 vs. hours 1-7 (AM=275±139, PM=583±259, p<.05). However, drinking frequency (drinks/hour) was similar from hours 1-7 vs. 8-15 (AM= 5.3±3.9, PM=7.4±3.3, p<.05). There was a significant decrease in nude body weight pre to post shift (AM=79.8±14.1, PM=79.1±14.2, p<.05). Similarly, urine specific gravity demonstrated a significant increase throughout the workshift (AM=1.019±0.006, PM=1.023±0.009, p<.05). However, self-selected workrate (mean activity counts/hr) was not significantly different between the early and later segments of the workshift (AM=502±223, PM=450±146, p<.05). Conclusion: These data demonstrate that extended arduous work in the heat is associated with a rise in ambient, core and skin temperatures and self-selected drinking volume. The similarity in hourly activity counts during the early and later segments of the workshift suggests that drinking behavior may be more related to temperature change than work rate. The reduction in BW and increase in urine SG suggests that although drinking volume increased throughout the day, it was not enough to maintain euhydration.

Dedication

To my parents whose endless love and support has helped guide me through this journey.

To my dear friends Bryan Nelson and Nate Stevens
Our friendships I will forever cherish. The lessons you have taught me and the memories
we have shared I will carry with me always.

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Chapter One

THE PROBLEM

Introduction

Wildland firefighters (WLFF) work long shifts in extreme environmental conditions. Many factors such as, fitness level, nutrition, temperature regulation, hydration, immune function, previous work assignments and acclimatization to the environment influence a WLFF's cognitive and physical performance.

Using the doubly labeled water (DLW) and heart rate methodologies our lab has recently determined the total energy expenditure during wildland fire suppression to be 12.6-26.5 MJ•d⁻¹ (3000-6300 kcal•d⁻¹) (Burks et al., 1998, Ruby et al., 2002). The activity associated with wildland firefighting suppression may involve strenuous hiking with a load (fire shelter, Pulaski fire line tool or chainsaw) and fire line construction. This data shows that wildland firefighters (WLFF) must be conscious of their dietary and water intake. Our data suggests that during arduous and extended workshifts energy expenditure can increase upwards of 3.6 times basal metabolic rate.

Our lab has also conducted studies measuring water turnover in the WLFF population. Working in an environment where the ambient weather, radiant heat from the fire, and extended length of the work shift influence hydration demands. Results from this study show that the WLFF has a tendency to lose total body mass and total body water during 5 days of wildfire suppression (Ruby et al., 2002). The rates of water turnover from ²H₂O elimination indicate that the minimal hydration demands of job are 6-8 liters of water •d⁻¹ from beverages and 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 which the WLFF exceed previously reported values 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).

Depending on environmental temperature, the relative contributions of evaporative and dry (radiative and conductive) heat exchange to the total heat loss vary. The hotter the environment the greater the dependence on evaporative heat loss, thus on sweating (Nielsen, 1938, Sawka et al., 2001). Therefore, in hot environments, a considerable amount of body water can be lost through sweat gland secretion to enable cooling of the body (Wenger, 1972). Water loss from the body can exceed 30g/min (1.8L/h) in heavy sweating conditions, therefore increasing risk of dehydration and overheating if necessary fluids are not replenished (Nadel et al., 1990). As a result of insufficient replacement of lost fluids, hypohydration may occur. This causes the individual to experience the inability to self-regulate body temperature, decrease cognitive functioning and work capacity (Sawka, 1992). Due to the potential danger of wildland firefighting, the ability to make quick decisions and work long shifts is important.

For each individual, sweat rate is dependent on environmental conditions (ambient temperature, dew point temperature, radiant load, wind speed), clothing (insulation and moisture breathability), and physical fitness level (Adolph et al., 1947,

Shapiro et al., 1982). Therefore, the individual adaptations that occur in these environments need to be considered.

During arduous work in the heat it is difficult to match the volume of fluid consumed to the volume of sweat output. Many studies have indicated that athletes' fluid intake practices were widely individual and generally insufficient to maintain adequate hydration during simulated events (Maughan et al., 2004, Iuliano et al., 1998). Research has also shown that the thirst mechanism is a poor indicator for the body's water requirements and that ad libitum drinking result in incomplete fluid replacements (Adolph et al., 1947, Engell et al., 1986). Because water is the largest component of the human body, representing 45-70% of body weight, it is important to maintain hydration. If adequate amounts of fluids are not consumed to replace sweating, a loss of total body water will occur (Sawka, 1992). Craig and Cummings (1966) demonstrated that small (2% body weight) to moderate (4% body weight) water deficits resulted in large reduction of maximal aerobic power. A study conducted by Sawka (1985) states that for euhydrated individuals environmental heat stress alone decreases maximal aerobic power by ~7%. Because exercise in the heat decreases blood volume, the re-distribution of blood to the skin (for cooling), could decrease aerobic power by, decreasing cardiac output (Sawka, 1992). This evidence concludes that WLFF's need to be aware of their hydration status to perform the aerobic tasks required.

Due to the nature of exercising in the heat many variables need to be considered to maintain work output and the safety of the individual. Although many of these variables differ between individuals, exploring the different drinking behaviors and physiological variables could provide helpful information to those involved.

Problem

The purpose of this investigation was to describe variations in physiological (work output, core and skin temperature) and behavioral (drinking patterns; intake/frequency) variables during arduous wildfire suppression.

Research Hypotheses

Hypothesis One:

There will be a significant decrease in body weight from am (hours 1-7) vs. pm (8-15).

Hypothesis Two:

There will be a significant increase in core body temperature (°C) from am (hours 1-7) vs. pm (hours 8-15).

Hypothesis Three:

There will be a significant increase in ambient temperature (°C) from am (hours 1-7) vs. pm (hours 8-15).

Hypothesis Four:

There will be a significant increase in skin temperature (°C) from am (hours 1-7) vs. pm (hours 8-15).

Hypothesis Five:

There will be a significant increase in activity from am (hours 1-7) vs. pm (hours 8-15).

Hypothesis Six:

There will be a significant increase in drinking (behavior) frequency from am (hours 1-7) vs. pm (hours 8-15).

Hypothesis Seven:

There will be a significant increase in drinking (behavior) volume from am (hours 1-7) vs. pm (hours 8-15).

Significance of the Study

Results from this study will encourage the United States Forest Service as well as military personnel, endurance athletes and coaches on the importance of individualizing a plan to maintain the safety of the individuals involved during heat stress.

Limitations

- i. **Non-randomized sample.** The sample will not be randomly selected. Subjects from various crews will be obtained on a volunteer basis.
- ii. **Instrumentation.** There is inherent error in all instrumentation. Having the same researchers download subject data and informing subjects on how to use equipment will minimize this error.
- iii. **Gender.** Females and males were subjects in this study. Previous research has shown that women tend to drink more than men in endurance events. This was not controlled for in this study due to the unequal sample sizes.

- iv. **Fitness Level.** It is assumed that the fitness levels of the subjects are reflective of the levels observed in wildland firefighters.

De-limitations

- i. **Type of subjects.** No restrictions will be made on age, gender, or ethnicity.
- ii. **Selection of subjects.** Only hotshot wildland firefighters and state agencies firefighters were selected for this study. This is due to the advanced training this group has compared to other levels of wild land firefighters.
- iii. **Years of experience.** Due to the knowledge that is gained through experience subjects were asked how many years of wildland firefighting experience they had.

Definition of terms

Euhydration. Normal body water content

Hypohydration. Dehydration of the human or animal body.

Hyponatriema. Deficiency of sodium in blood. <130mEq/L

Dehydration. The lack of body fluids for the body to carry normal functions at an optimal level (by loss, inadequate intake, or both).

Drink O Meter or Hydration Pack. Device use to measure fluid consumed. #

Drinks/hour, total mL/hour, mL/drink

Jonah™ Capsule. Ingestible core temperature sensor.

Hot Shot wildland firefighter. The highest category land crew in United States.

These men and women are usually given the toughest assignments when fighting fire. The crew members serve in all phases of wildland firefighting, building line fires, burning out, setting backfires and mopping up (National Office of Fire and Aviation).

Chapter Two

Review of Literature

From a physiological standpoint, one of the most severe stresses an athlete, soldier or wildland firefighter can encounter is work in the heat.

Although many sporting events are held in unfavorable environmental conditions, the burning forest is the workplace for wildland firefighters. These conditions make it imperative that the National Forest Service and crew bosses understand how to effectively acclimatize their men and women for work in the heat.

Exercise in the heat

About 75% of the energy during exercise is wasted as heat, inevitably causing body temperature to rise. In cool environments, much of the body heat can readily be transferred to the air (Nadel, 1988), but when ambient temperatures

exceed skin temperature, heat is gained and body temperatures rise. This is important to note because WLFF work in hot environments where the ambient temperature is can reach 115 degrees °C or more causing the body temperature to rise. As a result of exercising in the heat, blood flow to the skin is increased and results in the loss of body water and electrolytes in sweat (Hargreaves, 1996). Sweat loss can impair cardiovascular function and causes dehydration, which further compromises the body's ability to cool and accelerates the rise in core temperature. Replenishing water and electrolytes throughout the workshift is important to attenuate heat related disorders. These disorders can cause mental confusion and impaired physical work ability, which could be the difference between life and death for a WLFF.

Acclimation

Regular exposure to hot, humid conditions causes a number of physiological adaptations to occur. Such responses include an increase in blood volume and the enhanced ability to sweat (Murray et al., 2002). The increase in blood volume allows the body to keep up with the demand for blood from the muscles and skin. Acclimatization also results in the increase in sweat rate, a greater distribution of sweat over the body, and sweating will begin earlier and at a lower core temperature (Sutton, 1996). Also, the sodium and chloride content of sweat tends to be reduced with acclimatization as the body attempts to retain sodium to help conserve extracellular fluid volume. Kirby et al., (1986) reported

that over the course of heat acclimation the sweat sodium concentrations decrease, despite a 12% increase of sweating rate, the sodium losses decreased by 59%.

The rate at which acclimatization to work in the heat depends upon the intensity and duration of the exercise and on the environmental conditions. Most physiological adaptations occur within 7-14 days of regular exercise in the heat. (Montain, 1996). Again, improvements in heat tolerance are associated with increased sweat rates, a lower skin and body temperature, and a reduced heart rate (Febbraio et al., 1994). Consequently, there may be no advantage of living for prolonged periods in a hot climate (Montain et al., 1996). Sawka (1992) states that an individual's state of heat acclimation alters the degree of hypovolemia (decreased blood volume) associated with hypohydration.

Fitness Level

Some researchers have concluded that physical activity may not be necessary to achieve heat acclimatization but may contribute to the extent that it increases body temperature (Avellini et al. 1982, Edholm and Weiner 1981). Others have reported physiological changes compatible with heat acclimatization by mere physical conditioning in a neutral climate (Inhar et al, 1981, Smorawinski and Gucza, 1994).

Drinkwater et al., (1976) concluded that in conditions of severe heat stress (48° C) athletes were able to maintain a cardiac output sufficient to meet the metabolic requirements and large increase in peripheral blood flow for a longer period of time than nonathletes. Due to the long workshifts and the physical labor

involved of wildfire suppression, it is important for WLFF's to be able to keep up with the demands of the job. The United States Forest Service has a set of fitness requirements individuals must meet to become a WLFF. These requirements include a pack tests with consists of a 3-mile hike with a 45-pound pack on the subject's back that must be complete within 45 minutes. Individuals are put through rigorous training before setting out for the fireline.

Doubly labeled water is a gold standard and the reference for the validation of field methods to assess physical activity, but accelerometry is the most practical and lowest cost method of objectively monitoring human movement (Westerterp, 2004). Ruby et al. (2002) suggests that wildfire suppression requires an average daily energy expenditure equivalent to approximately 2.5-3.0 x BMR (basal metabolic rate). Therefore, the physical activity during multiple days of wildfire suppression may range from 4.2 to 12.6 MJ•d⁻¹. During wildland firefighting, the WLFF's activity ranges throughout the workshift. The draw back to using accelerometry to predict energy expenditure is that different activities require different equations.

Physiology and hydration state

Reasonable figures for the daily water loss are as follows: from gastrointestinal tract, 200 ml, respiratory tract 400ml, skin 500ml, kidneys 1,500ml, totaling 2600ml. This loss is balanced by intake as follows: fluids, 1,300ml, water in food 1,000ml, water liberated during the oxidation in cells 300ml, totaling 2,600ml. However, the water loss can increase considerably

when the individual is exposed or exercising in the heat (Astrand et al., 2003). Ekblom et al., 1970 found that a deficit of only 1% of body weight elevates core temperature during exercise. As the level of water deficit increases, there is an associated elevation of core temperature when exercising in the heat (Montain and Sawka, 2000). The magnitude of core temperature elevation ranges from 0.1° to 0.25° for every percent body weight lost (Adolph 1947, Sawka 1992). In three of five studies when hypohydration equaled or exceeded 3% body weight, maximal aerobic power was decreased (Buskirk 1958, Caldwell, 1986, Webster, 1988). In a hot environment, Craig and Cummings (1966) demonstrated that a small (2% body weight) to moderate (4% body weight) water deficits resulted in large reduction of maximal aerobic power. Therefore, it seems that environmental heat stress has a potentiating effect on the reduction of maximal aerobic power elicited by hypohydration.

Many studies have concluded that hydration state can effect cognitive functioning. 1-2 % dehydration state can compromise cognitive function (Armstrong et al., 1999). Cian et al. (2000, 2001) demonstrated that dehydration results in an increase perceptual task reaction time (without a change in error rate), decrease tracking performance and psychomotor skills, a decrease short-term, but not long term memory. The detrimental effects on short-term memory are alleviated 3.5 following rehydration (following dehydration), subjects feel less tired, and long-term memory is improved compared to those whose hydration status is held constant (euhydration), but decision making time in perceptive discrimination test does not improve (Cian et al., 2001). Furthermore,

hyperhydration significantly improves short-term memory compared to euhydration (Cian et al., 2000). Due to the dangerous nature of wildland firefighting, it is important be able to make the right decision fast.

Palatability of the beverage is an important factor in maintaining hydration and rehydrating. Many individuals may lose substantial amounts of sweat and will therefore need to replenish these stores with large amounts of fluids and this is more likely to be achieved if the taste and temperature is perceived as pleasant. Wilk and Bar-O (1996) gave subjects one of three beverages (chilled to 8-10 degrees °C). The beverages were unflavored water, grape-flavored water and grape-flavored water plus 6% carbohydrates and 18mmol/l NaCl. Subjects drank ad libitum. They concluded that the flavoring of water reduced voluntary dehydration, further addition of carbohydrate and sodium prevents it altogether. Another study conducted by Clapp et al., (1999), showed that subjects who ingested just water had a greater weight loss than those subjects who ingested carbohydrate electrolyte beverage. This data suggests that a greater rate of dehydration occurred when only water was used for fluid replacement.

To achieve hydration and effective rehydration following exercise in the heat, the beverage should contain moderately high levels of sodium (50mmol l⁻¹), and possibly some potassium. The addition of a substrate is not necessary for rehydration, although a small amount of carbohydrate (<2%) may improve the intestinal uptake of sodium and water (Maughan, 1997).

Chapter Three

METHODOLOGY

Setting

Testing took place in Leavenworth, Washington during the Fischer Fire during the Fire season of 2004.

Subjects

The subjects for this study consisted of 20 wildland firefighters (16 male, 4 female). All subjects were volunteers from various hotshot and district crew and were required to read and sign a University of Montana IRB approved consent form before testing began.

Descriptive Data

All subjects were asked to complete a questionnaire. Descriptive data was collected on gender (male/female), age (years), height (inches), and years of fire experience.

Pre-trail Measures

At 0430 each morning, the four testing subjects collected their first urine sample after which a nude body weight was measured. After the collection of body weight, subjects ingested a "Johus Capsule" (Mini Mitter, Bend, OR), which measured core temperature and had a skin temperature sensor placed on the lateral side of the left deltoid. An additional sensor was placed on the outside of the vitalsense monitor holster, which was worn on the subject's belt. Prior to testing subjects weight and an am urine void were collected.

After subjects ate breakfast, they were provided with specially outfitted hydration systems (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). Before leaving for their workshift, subjects were instructed to work their entire shift while consuming all fluid through the drinking system (water only).

During the workshift, subjects collected urine at approximately 1030, 1500 and 1-hour post shift. Urine samples were evaluated for specific gravity using a hand held refractometer calibrated to distilled water.

Activity Monitoring

Each day of the study, subjects were instructed to wear Actical™ activity monitors in the front pocket of their shirt during the workshift to measure physical activity. These Actical activity monitors recorded movement left to right, front to back and up/down. Activity was reported in counts per hour.

STATISTICAL PROCEDURES

Descriptive data were reported as mean \pm standard deviations (SD) for the following variables. All descriptive data were analyzed using a t-test. Significance was set at $p < 0.05$.

CHAPTER FOUR

RESULTS

Descriptive Data

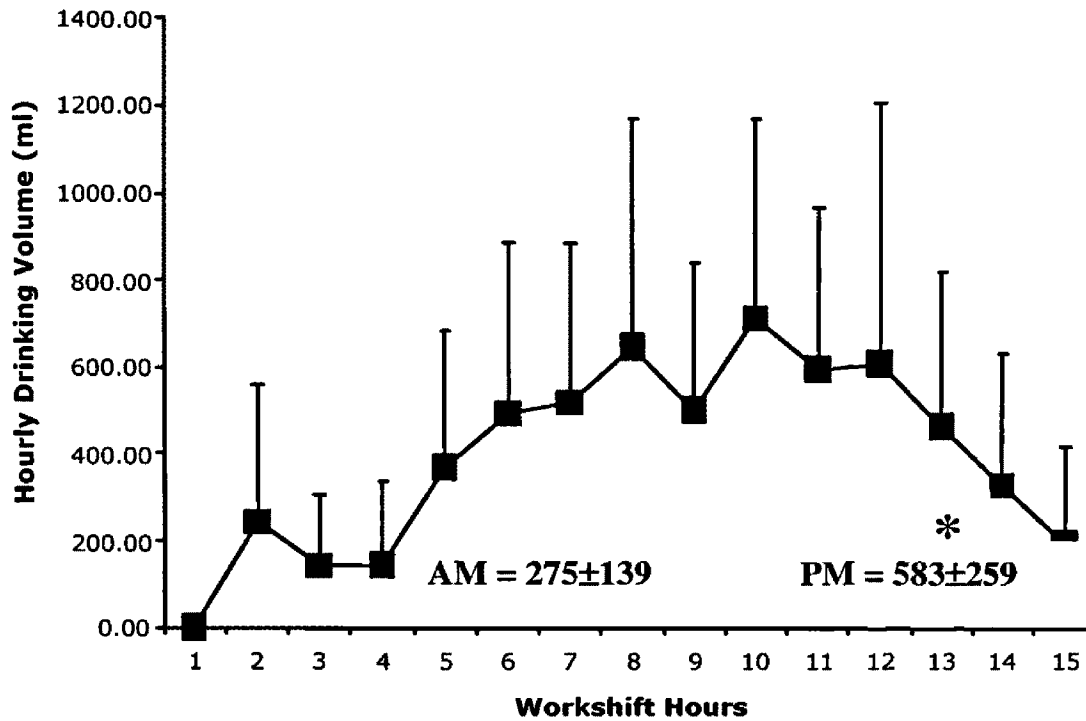
Sixteen male subjects and four female subjects participated in the study. All subjects met the criteria for fitness and signed and IRB approved consent form. Table 1 shows subject descriptive data.

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

Age (years)	25.5 \pm 6.0
Body Weight (kg)	79.3 \pm 13.9
Height (cm)	178.8 \pm 9.0
Wildfire experience (years)	4.9 \pm 5.6

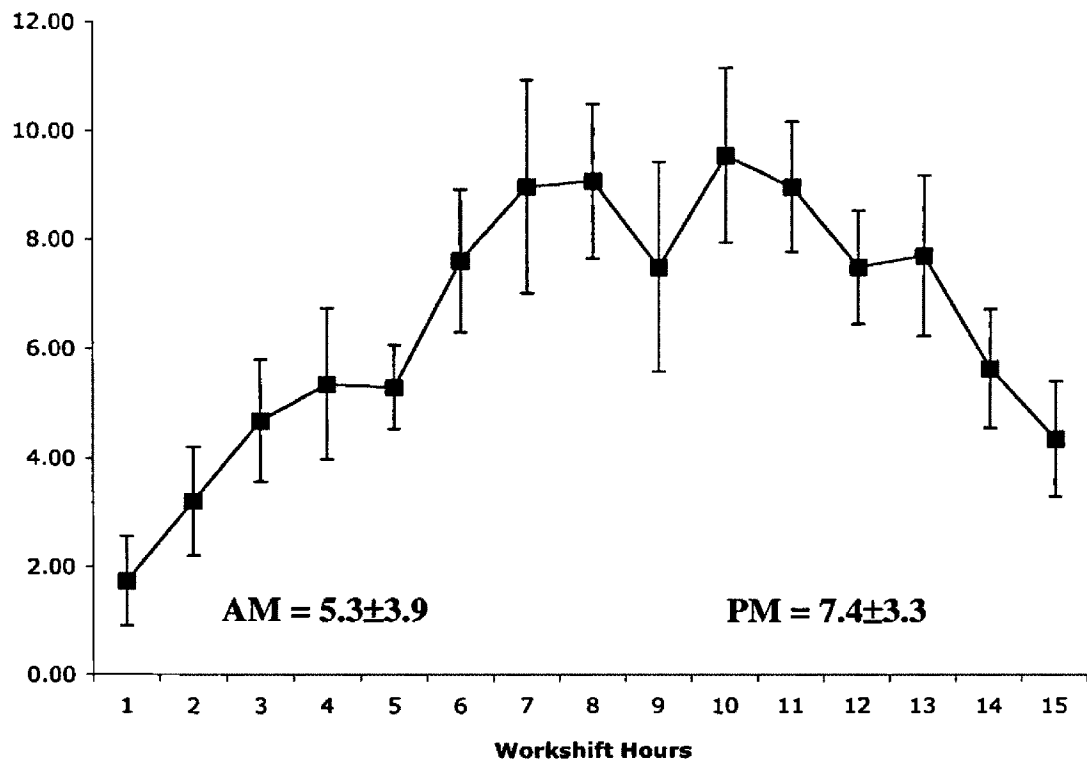
Hydration

Drinking behaviors were measured using the drink O meter system. A significant difference was found between the amount of fluid (Liters/hour) consumed between AM = 275 \pm 139 vs. PM = 583 \pm 259 (* p <0.05). Figure 1. represents drinking volume (ml/hour) across the workshift. Peak consumption occurred in the later part of the workshift. There was no significant difference were found between AM and PM drinking frequency (AM= 5.3 \pm 3.9 drinks/hour, PM= 7.4 \pm 3.3 drinks/hour). Figure 2 represents drinking frequency (# of drinks/hour).



*p < 0.05 vs. AM, AM=mean of hours 1-7, PM=mean of hours 8-15

Figure 1. Drinking volume. Values presented represent total hourly consumption (ml) computed from the digital drinking systems and expressed as mean ± SD.

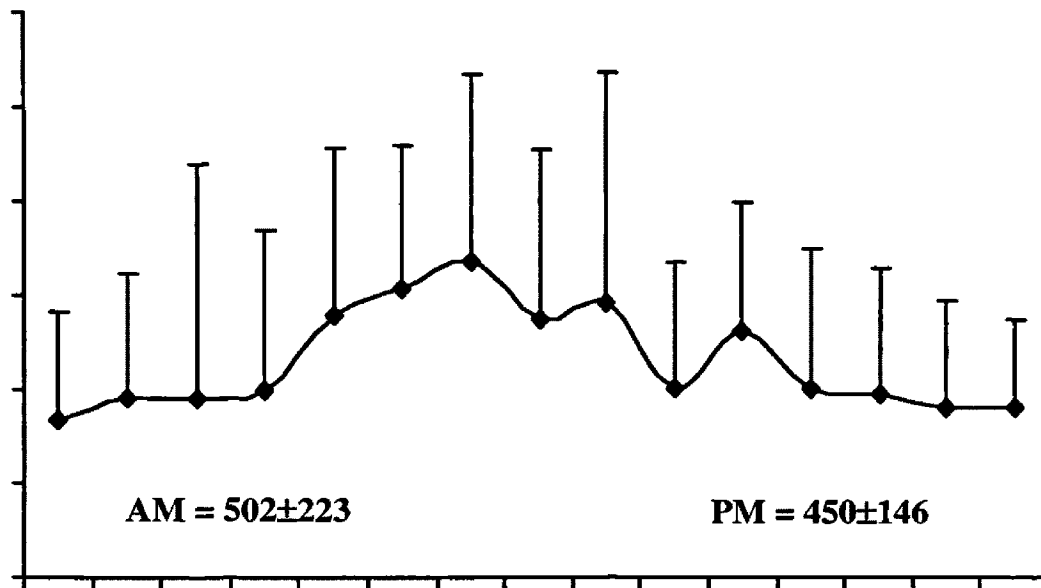


AM = mean of hours 1-7, PM = mean of hours 8-15

Figure 2. Changes in drinking frequency (# drinks/hour) during workshift. Values presented are represented in the number of drinks taken each hour from the digital drinking system and expressed as mean \pm SD.

Activity

There was no difference between AM vs. PM for activity. Figure 3. Shows variation in activity (counts/hour) throughout the workshift.

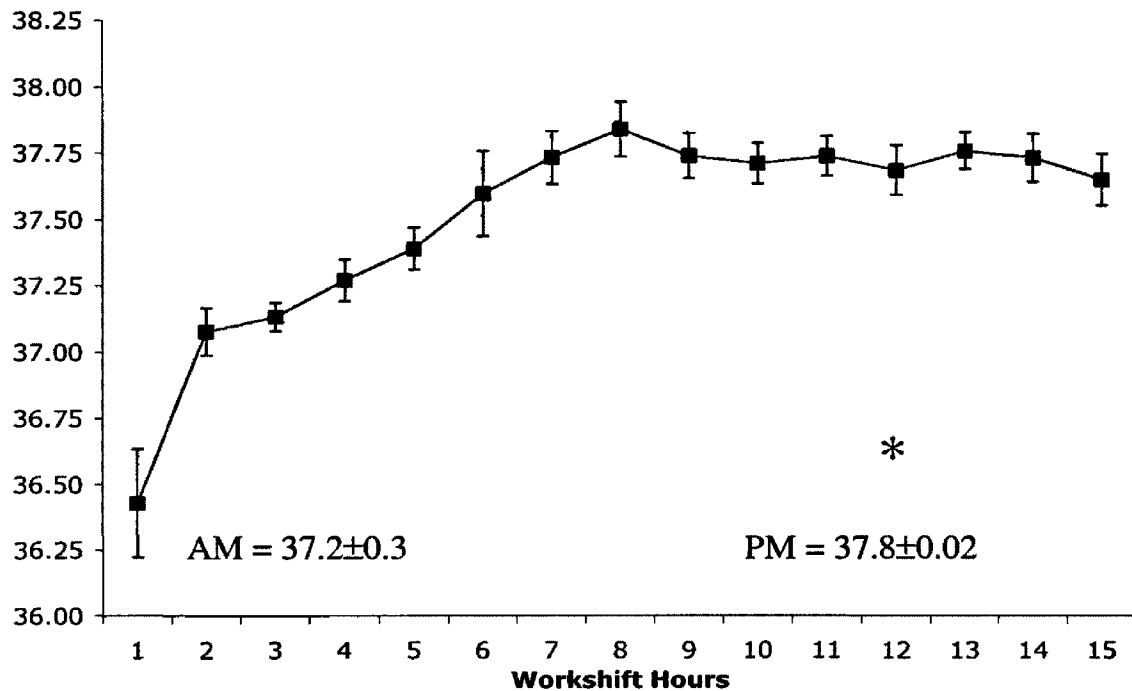


AM = mean of hours 1-7, PM = mean of hours 8-15

Figure 3. Variations in activity monitor counts (average hourly counts) during workshift and expressed as mean \pm SD.

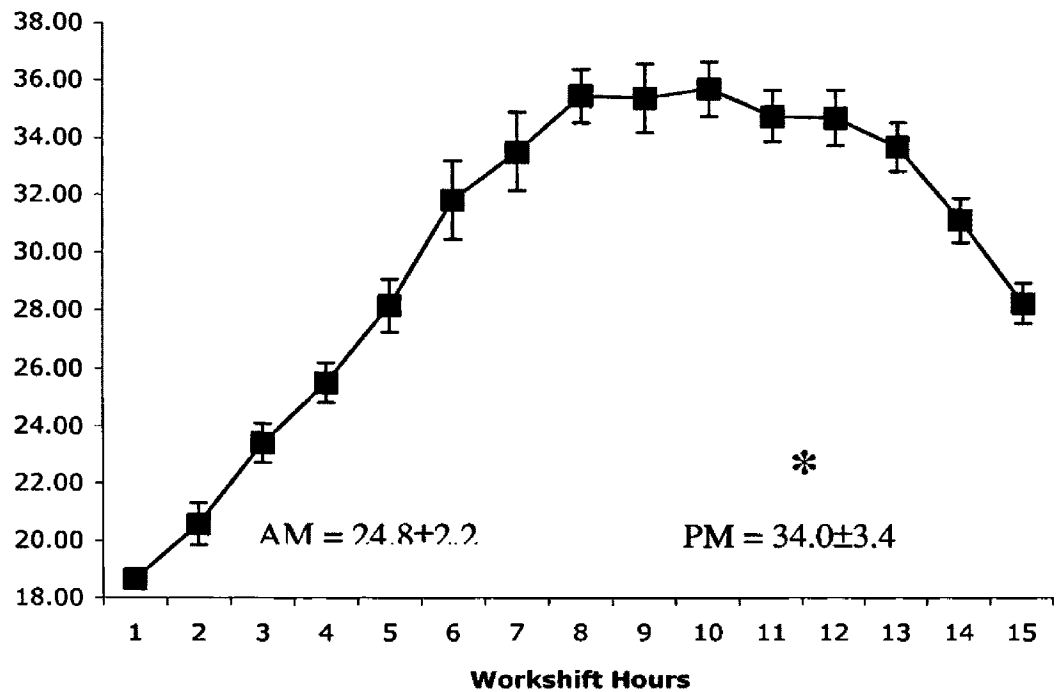
Temperature

A significant difference was found in core temperature ($^{\circ}\text{C}$) between AM vs. PM (AM= 37.2 ± 0.3 , PM= 37.8 ± 0.02), $*p<0.05$. Changes in core temperature are shown in Figure 4. There was also a significant difference in ambient temperature ($^{\circ}\text{C}$) between AM vs. PM (AM = 24.8 ± 2.2 , PM = 34.0 ± 3.4), $*p<0.05$. Changes in ambient temperature are shown in Figure 5. Skin temperature was significantly higher in the PM vs. the AM (AM= 32.7 ± 1.2 , PM= 34.67 ± 1.3), $*p<0.05$.



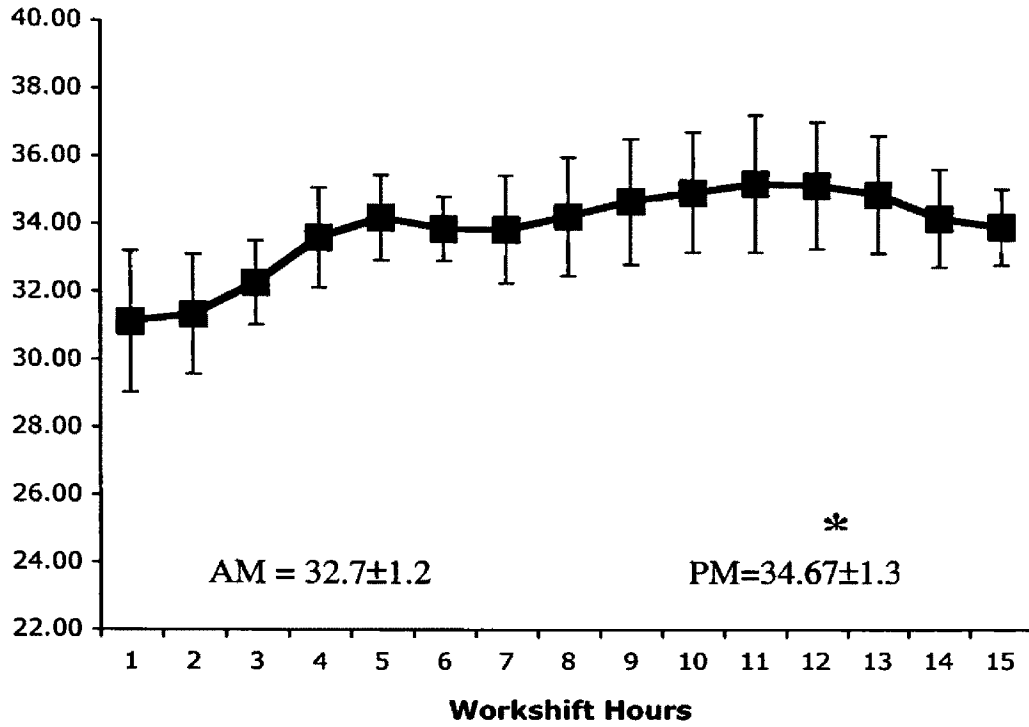
$*p<0.05$ vs. AM, AM= Hours 1-7, PM = Hours 8-15

Figure 4. Changes in core temperature ($^{\circ}\text{C}$) during workshift. Values presented are average hourly computed from 60 values (1min collection cycle) and expressed as mean \pm SD.



* p < 0.05 vs. AM, AM=mean of hours 1-7, PM=mean of hours 8-15

Figure 5. 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 ± SD.



* $p < 0.05$ vs. AM, AM=mean of hours 1-7, PM=mean of hours 8-15

Figure 6. 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 \pm SD.

Urine Osmolality

Significant differences were found in urine osmolality between AM vs. PM. Urine osmolality is represented in Figure 7.

AM	1.019±0.005
PM	*1.023±0.009

Figure 7. Urine Osmolality. Values expressed as mean ± SD.

Body Weight

There was a significant difference between body weight changes pre vs. post. Changes in body weight are shown in Figure 8.

PRE	79.79±14.10
POST	*79.09±14.21

Figure 8. Pre and Post Shift Body Weights. Values expressed in kg as mean ± SD.

REFERENCES:

Adolph, E.F. and associates. *Physiology of Man in the Desert. New York: Interscience.* 1947.

Armstrong, L.E., Epstein, Y. Fluid-electrolyte balance during labor and exercise: concepts and misconceptions. *Int J Sports Nutr* Mar 9(1): 1-12 1999.

Burks, C.A., B.J. Sharkey, S.A. Tysk, T.W. Zderic, S.L. Johnson and B.C. Ruby. Estimating energy expenditure in wildland firefighters using heart rate monitoring and physical activity records. *Med. Sci. Sports Exerc.* 30:S56, 1998.

Buskirk, E.R., P.F. Iampietro, and D.E. Bass. Work performance after dehydration: effects of physical conditioning and heat acclimation. *J Appl. Physiol.* 12:189-194, 1958.

Caldwell, J.E., E. Ahonen, and U. Nousianen. Differential effects of sauna diuretic-, and exercise-induced hypohydration. *J Appl Physiol.* 57:1018-1023, 1984.

Cian, C., B. Barraud, B. Melin, and C., Raphel. Effects of fluid ingestion on cognitive function after heat stress or exercise induced dehydration. *International Journal of Psychophysiology*, 42(3), 243-251, 2001.

Cian, C., N. Koulmann, P. Barraud. Influence of variations in body hydration on cognitive function: Effect of hyperhydration, heat stress, and exercise-induced dehydration. *Journal of Psychophysiology.* 14(1), 29-36, 2000.

Clapp, A.J., Bishop, P.A., Walker, J.L. Fluid replacement preferences in heat-exposed workers. *Am Ind Hyg Assoc J.* Nov-dec: 60(6): 747-51, 1999.

Craig, F.N., and Cummings E.G. Dehydration of muscular work. *J Appl Physiol.* 21: 670-674. 1966.

Drinkwater, B.L., Denton, J.E., Kupprat ,I.C, Talag, T.S., Horvath, S.M. Aerobic power as a factor in women's response to work in hot environments. *J Appl Physiol.* 41(6), 815-21, 1976.

Elblom, B., C.J. Greenleaf, J.E. Greenleaf and L. Hermansen, L. Temperature regulation during exercise dehydration in man. *Acta Physiol. Scand.* 79, 475-483, 1970.

Engell, D.B., Maller, O., Sawka, N, Francesconi, R.P. Thirst and Fluid intake following graded hypohydration levels in humans. *Physiol Behav.* 40:226-236, 1986.

Febbraio, M.A., Snow R.J., Hargreaves, M. Stahis C.G., Martin, I.K., Carey, M.F. Muscle metabolism during exercise and heat stress in trained men: effect of acclimation. *J Appl Physiol.* Feb 76(2): 589-97, 1994.

Fusch, C. W. G. Frorer, C. Koch, A. Thomas, A. Grunert, and H. Moeller. Water turnover and body composition during long-term exposure to high altitude (4,900-7,600m). *J Appl. Physiol.* 80:1118-1125, 1996.

Fusch, C.W., H. Dickhuth, and H. Moeller. Physical fitness influences water turnover and body water changes during trekking. *Med. Sci. Sports Exerc.* 30:704-708, 1998.

Hargreaves, M. Exercise Performance in the Heat. (1996) April 24, 2005.
<http://www.gssiweb.com/reflib/refs/79/d0000000200000040.cfm?pid=38>

Iuliano, S., Naughton, G., Collier, G., Carlson, J. Examination of the self-selected fluid intake practices by junior athletes during a simulated duathlon event. *Int J Sport Nutr.* 8(1): 10-23, 1998.

Kirby, C.R. and Convertino, V.A. Plasma aldosterone and sweat sodium concentration after exercise and heat acclimation. *J Appl Physiol.* 61:967-970, 1986.

Maughan, R.J., S.M. Shirreffs, Recovery from prolonged exercise: restoration of water and electrolyte balance. *J Sports Sci.* 15(3):297-303, 1997.

Maughan R.J., Merson, S.J., Broad, N.P., Shirreffs, S.M.. Fluid and electrolyte intake and loss in elite soccer players during training. *Int J Sport Nutr Exerc Metab.* 14(3): 333-46, 2004.

Montain, S.J., E.F. Coyle. Influence of graded dehydration on hyperthermia and cardiovascular drift during exercise. *J Appl Physiol.* 73(4), 1340-50, 1992.

Murray, B., E. Randy Eichner, John Stofan (2003). Hyponatremia in Athletes. January 2, 2005. http://www.gssiweb.com/reflib/refs/604/SSE_88_Content.cfm?pid=38

Murray, B. (2002). Preventing Dehydration: Sports Drinks or Water. January 2, 2005.
http://www.gssiweb.com/reflib/refs/701/Science_of_sports_drinks.cfm?pid=38

Ruby, B.C., D.A. Schoeller, and B.J. Sharkey. Evaluation of total energy expenditure (doubly labeled water) across different measurement periods during arduous work. *Med. Sci. Sports Exerc.* 34:1048-1054, 2002.

Ruby, B.C., D.A. Schoeller, B.J. Sharkey, C. Burks and S.A. Tysk. Water turnover and changes in body composition during arduous wildfire suppression. *Med. Sci Sports Exerc.* 1760-1765, 2003.

Sawka, M.N., Young, A.J., Cadarette, B.S., Levin, L. Influence of heat stress and acclimation on maximal aerobic power. *Eur J Appl Physiol.* 53:294-298, 1985.

Sawka, M.N. Physiological consequences of hydration: exercise performance and thermoregulation. *Med. Sci. Sports Exerc.* 24, 657-670, 1992.

Sawka, M.N., S.J. Montain, and W.A Latzka. Hydration effects on thermoregulation and performance in the heat. *Comparative Biochemistry and Physiology-Part A: Molecular and Integrative Physiology.* Volume 128, Issue 4, 679-690, 2001.

Sawka, M.N., and Montain, S.J. Fluid and electrolyte supplementation for exercise heat stress. *Amr J Clin Nutr* Vol 72, No 2, 564-572. 2000.

Shapiro, Y., Pandolf, K.B. and Goldman, R.F., 1982. Predicting sweat loss response to exercis, environment and clothing. *Eur. J Appl Physiol* 48, pp83-96, 1982.

Sutton, J. (1996). Exercise Performance in the Heat. December 4, 2004.
<http://www.gssiweb.com/reflib/refs/79/d0000000200000040.cfm?pid=38#4>

Webster, S.F., R.A Rutt, and A. Welstman. 1988. Effects of typical dehydration practices on perfomance. *Med Sci. Sports Exerc.* 20:S20, 1988.

Wenger, C.B. Heat of evaporation of sweat: thermodynamic considerations. *J Appl Physiol.* 32(4): 456-9, 1972.

Westerterp, K.R., Plasqui, G. Physical activity and human energy expenditure. *Curr Opin Clin Nutr Metab Care.* 7, 2004.

Wilk, B., and O. Bar-Or. Effect of drink flavor and NaCl on voluntary drinking and hydration in boys exercising in the heat. *J. Appl. Physiol.* 80: 1112-1117, 1996.

Effects of Electrolyte Additives to Water on Changes in Body Temperature and Drinking Behavior During Arduous Wildfire Suppression

J.A. Ham, S.G. Harger, S.E. Gaskill and B.C. Ruby

Address for correspondence: Brent C. Ruby

Director, Human Performance Laboratory

The University of Montana, Department of Health and
Human Performance, McGill Hall, Missoula, MT 59812,

USA Telephone:

Telephone: (406) 243 2117

Fax: (406) 243 6552.

email: brent.ruby@mso.umt.edu

Abstract. Wildland firefighters (WLFF) work long shifts in extreme environmental conditions. Temperature regulation and hydration status are important factors that can affect, cognitive and physical performance during extended workshifts. **PURPOSE:** The purpose of this investigation was to describe the effects of electrolyte additives to water on changes in body temperature, hydration status and drinking behavior during arduous wildfire suppression. **METHODS:** Subjects (n=16 males, n=4 females wildland firefighters from various Hot Shot and District crews) participated in a between subjects design. Subjects randomly received either water alone or water and an electrolyte additive (45 mg Magnesium, 125 mg Sodium, 390 mg Chloride, 130 mg Potassium, and

20 mg Sulfate per liter) throughout the day. Core, skin, and ambient temperatures were measured using a wireless physiology monitoring system. Drinking characteristics (volume, rate, frequency) were recorded with a digital flow meter built into a modified sipping drinking system. Urine specific gravity was determined four times during the day. Data were analyzed using a two way mixed design (treatment x time) repeated measures ANOVA to evaluate changes across the workshift between the groups. **RESULTS:** Ambient temperature exposure was similar between groups. No significant differences were found in core and skin temperatures between water + E and water groups. There was also no significant difference in drinking frequency across the groups. Although, there was not a significant difference in the change in workshift body weight between the two groups, total drinking volume was significantly less for the water + E group (4.3 ± 1.8 and 7.5 ± 2.3 L for the water and E and water groups, respectively). No differences were found in urine specific gravity between the groups. **CONCLUSION:** These current data suggest that when water is treated with small of amounts of supplemental electrolytes, less water is required to maintain whole body hydration during arduous work.

Additional keywords: wildland fire suppression; firefighting; hydration status

Brief Summary: This investigation shows variations in ad libitum drinking behavior may be effective by physiological and environmental conditions, such as ambient temperature and alterations in core temperature. These current data also suggest that when water is treated with a small amount of a supplemental electrolyte it may help attenuate dehydration.

Introduction

Wildland firefighters (WLFF) work long shifts in extreme environmental conditions. Many factors such as fitness level, nutrition, temperature regulation, hydration status, immune function, previous work assignments and acclimatization to the environment influence can affect cognitive and physical performance.

Using both the doubly labeled water (DLW) and heart rate methodologies our lab has recently determined total energy expenditure during wildland fire suppression to be 12.6-26.5 MJ·d⁻¹ (3000-6300 kcal·d⁻¹) (Ruby et al., 2002). These data show that WLFF must be careful to maintain adequate caloric intake. Additionally, the extended work in a hot and dry environment means the WLFF must properly hydrate as well. Ruby et al. (2002) suggests that during arduous and extended workshifts energy expenditure can increase as high as of 3.6 times basal metabolic rate.

Our laboratory previously conducted a water turnover study in this population to more clearly understand the hydration demands of the wildland firefighting (Ruby et al., 2003). The results from this hydration study demonstrate that the WLFF has a tendency to lose both 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 demands are extreme and the subjects consumed approximately 6-8 liters of water·d⁻¹ from beverages and other food sources. The range of ²H₂O was 74-136.8 ml·kg⁻¹·d⁻¹ (mean 94.8±20.1 ml·kg⁻¹·d⁻¹) for the WLFF and exceeded values reported during trekking (79±17 ml·kg⁻¹·d⁻¹, 83±17 ml·kg⁻¹·d⁻¹ respectively) reported by Fusch et al. (1996, 1998).

Research has shown that fluid-electrolyte balance is a major concern for work or exercise lasting longer than 3-4 hours in the heat. Consumption of fluids containing electrolytes may attenuate the onset of heat-related illnesses (Armstrong et al., 1999). Maughan et al., (1997) states that for effective rehydration, fluids should contain moderately high levels of sodium (perhaps as much as 50-60mmol/l) and potassium to replace losses in the sweat. Because of the glucose-sodium co-transport system, the addition of a small amount of carbohydrate (< 2%) may improve the rate of intestinal uptake of sodium and water.

Although our past research has clearly indicated a harsh working environment that challenges energy balance and hydration status, we have not previously collected core and skin temperature data across the extended workshifts. This lack of data has mainly been due to a lack of available technology enabling functional and comfortable methodologies to monitor core and skin temperatures in the field. New technologies have now made it possible to collect reliable and valid data.

The purpose of this investigation was to describe the effects of electrolyte additives to water on changes in body temperature, hydration status and drinking behavior during arduous wildfire suppression.

Methods

Subjects

Sixteen males and four females served as subjects in this investigation. Four subjects were monitored on each of 5 collection days. Subjects were randomly placed in one of two groups (water only or electrolyte additive and water). Prior to data collection,

subjects provided written consent approved by the University Internal Review Board.

Descriptive data is shown in Table 1.

Fluid Delivery and Measurement

Subjects (n=20) were randomly placed into either water alone or water and electrolyte additive (45 mg Magnesium, 125 mg Sodium, 390 Chloride, 130 mg Potassium, and 20 mg Sulfate per liter) groups. Subjects were informed to only drink out of their modified hydration systems (fluid reservoir drinking system) during the workshift. The drinking systems were re-filled as necessary during the workshift to allow for ad libitum drinking.

Hydration Systems

Subjects were provided with a specially outfitted hydration backpack (3L capacity modified Camelback, reservoir drinking system). Each system was equipped with a validated digital flowmeter system affixed inline to allow for the measurement of drinking characteristics (drinking frequency and drinking volume). Upon deployment, subjects were instructed to work their entire shift while consuming all fluid through the drinking system (water only or electrolyte (E) and water). Additional foods were allowed ab libitum throughout the shift. Subjects were instructed on how to refill the drinking system with additional water and E + water as needed. Every time subjects re-filled their 3L hydration systems with water, they were instructed to empty a vial containing water only or the water and electrolyte additive into their hydration systems.

Body Weight Measurements and Urine Collection

At 0430 upon awakening subjects were required to collect their first urine void after which a nude body weight was obtained (PS6600T, Befour Inc, Cedarburg, WI). A similar body weight was taken immediately post shift. During the workshift, subjected collected a urine void at approximately 0730 and additional samples at approximately 1030, 1500 and 1-hour post shift. Urine samples were evaluated for specific gravity using a hand held refractometer (Atago Uricon-NE, Farmingdale, NY) calibrated to distilled water.

Temperature Sensors

At 0500 subjects ingested a core temperature capsule (Jonah Capsule™, MiniMitter, Bend, OR) 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 workshift. An additional surface temperature sensor was placed on the outside of the monitor holster, which was worn on the subject's belt to measure ambient temperature. Subjects were then allowed to consume the normal breakfast provided at the fire camp.

Activity

Subjects were give Actical™ activity monitors in the front pocket of their shirt during the workshift to measure self-selected physical activity. These activity monitors recorded

movement patterns in all directions. Activity from the monitors was reported in counts·hour⁻¹.

Statistical Analyses

Data were analyzed using a series of mixed design ANOVA's with repeated measures (treatment x time) to evaluate changes across the workshift and between the water and electrolyte groups. Statistical significance was set at $p < 0.05$.

Results

Ambient Temperature

There were no differences in the ambient temperature conditions experienced between treatment groups. The main effect of time indicated that ambient temperature was significantly elevated for hours 4-15 compared to the first hour of the workshift (workshifts were 15 hours) ($p < 0.05$). Changes in ambient temperature are shown in Figure 1.

Core Temperature

There were no differences in the core temperature conditions experienced between treatment groups. The main effect of time indicated that core temperature was significantly elevated for hours 2-15 compared to the first hour of the workshift ($p < 0.05$). Changes in core temperature are shown in Figure 2.

Skin Temperature

There were no differences in the skin temperature conditions experienced between treatment groups. The main effect of time indicated that skin temperature was significantly elevated for hours 4-15 compared to the first hour of the workshift ($p < 0.05$). Changes in skin temperature are shown in Figure 3.

Drinking Behavior

There was no difference at any time point in drinking frequency ($\text{drinks}\cdot\text{hour}^{-1}$). However, there was a significant main effect for time ($p < 0.05$). Although there were no differences across the water and the water + E groups, overall data demonstrates a significant increase in drinking frequency during hours 8-13 compared to the second hour of the workshift. Changes in drinking frequency ($\text{drinks}\cdot\text{hour}^{-1}$) are shown in Figure 4. Figure 5 represents the average hourly intake ($\text{ml}\cdot\text{hour}^{-1}$). There was no difference at any time point in drinking volume. However, the main effect for time was significant ($p < 0.05$) demonstrating an increase in hourly intake from hours 6-13 compared to 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 main effect for treatment ($p < 0.05$). The average hourly intake was significantly higher for the water compared to the water and E group (7500 ± 2300 and 4300 ± 1800 ml for the water and water + E groups, respectively).

Body Weight

The main effect for time was significant for the measure of body weight ($p < 0.05$). Body weight showed a significant decrease over the workshift (AM = *water* 81.77 ± 16.54 , *water + E* 78.02 ± 11.51 , PM = 81.35 ± 16.35 , 77.06 ± 11.87). However, there were no differences between groups. Table 1. shows subjects descriptive data. Table 2. shows difference in body weight changes.

Activity

The main effect for time was significant for self-selected work output ($p < 0.05$). Activity patterns demonstrate significantly higher counts throughout the day at hours 6-8 (*water*- 3297.6 ± 1515.9 , *water + E* 3656.1 ± 1140.5 counts·hour⁻¹) compared to the initial hour of the workshift. However, there were no differences between the water and water + E groups. Self-selected work rates are shown in Figure 6.

Urine Osmolality

The main effect for time was significant for urine osmolality (AM = 1.019 ± 0.005 , PM = 1.023 ± 0.009) ($p < 0.05$). There was no differences between the water and E + water groups. Urine osmolality is represented in Table 3.

Discussion. The purpose of this investigation was to describe the effects of electrolyte additives to water on changes in body temperature and drinking behavior during arduous wildfire suppression. The main findings of this study suggest that adding supplemental electrolytes to normal drinking water may help reduce the overall fluid intake during

arduous working conditions in the WLFF. Although minimal differences were noted in weight loss between the groups, the total drinking volume was significantly different between the groups (water, 7.5 ± 2.3 L, water and E 4.3 ± 1.8 L). This significant difference indicates that the water and E group consumed an average of 3.2 L less than the water group. This fluid difference was in spite of similar self-selected work rates. Average activity rates peaked at hour 7 during a 15-hour workshift. Rates during this hour reached counts of 676 ± 400 . Average core temperature peaked at hour 9 ($37 \pm 0.05^\circ\text{C}$) but similar temperatures were recorded for hours 8 and 10 ($37.81 \pm 0.36^\circ\text{C}$ and $37.81 \pm 0.35^\circ\text{C}$, respectively). Peak average ambient temperature was recorded at hour 8 ($36.4 \pm 5.5^\circ\text{C}$). This appears to illustrate that the core temperature response appears to be a function of an increase in ambient temperature. Based on the actual activity data subjects tend to self-select a harder work output until the ambient temperature increase, and then a reduction in activity was recorded.

Latzka and Montain. (1999), states that daily fluid requirements range from 2 to 4 L·day⁻¹ in cool condition and up to 8-16 L·day⁻¹ very hot climates. Additionally, daily sodium requirements increase from 2 to 4 g·day⁻¹ to 6-12 g·day⁻¹ as temperatures increase.

Sodium consumption for the average American diet is ~5g·day⁻¹, which implies that supplementation, is generally not necessary. When physical activity increases, the additional caloric intake associated with increased activity covers the additional sodium requirements. However, during strenuous work in a heated environment, lost water and electrolytes must be replaced in order to maintain output. Sweat sodium loss of 2,500 to 5,000 mg is common among athletes with high sweating rate (example, 2.5L·hour⁻¹).

With each liter of water subjects in the water plus electrolyte group ingested 125 mg of

sodium. This group consumed 4.3 ± 1.8 L of water throughout the workshift, therefore, they consumed approximately 500 mg of sodium while drinking approximately 4 L of water. This small amount of sodium does not meet the RDA's recommended amount alone, but the meals provided by the Forest Service tend to be highly processed and contain enough sodium to meet the requirements.

Fluid and electrolyte balance are essential to optimal physiological function. A critical problem during exercise in the heat is to minimize dehydration by closely matching fluid consumption to sweat losses. Unless fluids are replaced, dehydration will occur during exercise in the heat (Sawka et al., 2001). In a dehydrated state, physical and cognitive performance is impaired at as little as 1-2%. Due to the demands and dangers of wildland firefighting it is important that firefighters are alert and physically capable to perform the duties required.

However, there are also health concerns associated with the consumption of excess water. Hyponatremia is the most common fluid and electrolyte disorder observed in the hospital setting and is becoming a greater concern in those participating in endurance events (Johnson, 2003). Hyponatremia is defined as abnormally low plasma sodium concentration (< 130 mmol/L) (Johnson, 2003). In 2002, Almond et al., (2005), studied 766 runners participating in the Boston Marathon. Of the 766 runners, 488 (64%) provided usable blood samples at the finish line. Thirteen percent had hyponatremia, 0.6% had critical hyponatremia (120 mmol per liter or less). This study concluded that hyponatremia was associated with substantial weight gain, consumption of more than 3 liters of fluid during the race, consumption of fluids every mile, a racing time of $>4:00$ hours, female sex, and low body-mass index. Therefore, those working at a lower

intensity in the heat need to be aware of the amount of fluids they are consuming so they do not overhydrate.

Often times during arduous field conditions, water availability is limited because of the logistics associated with cost, transport and purification. These data indicate that when water is treated with a small amount of supplemental electrolytes, less fluid may be required to maintain whole body hydration. Subjects did comment that the taste of the E and water was less desirable. Research has shown that the palability of a beverage may influence drinking behaviors. Subjects commented that they felt the unpleasant taste down-regulated their intake patterns. However, the water only group also mentioned the warmth of the water due to the use of the reservoir hydration systems was not desirable. 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 and urinary markers of specific gravity.

Conclusion

These data demonstrate alterations in ad libitum drinking behavior that parallel select physiological and environmental measures. Drinking frequency and volume appear related to ambient temperature and alterations in core temperature; therefore, when limited water resources are available, an electrolyte solution or a commercially available sports drink containing electrolytes may help attenuate dehydration and decrease the amount of required hourly intake to maintain normal hydration. Areas of future research should include the comparison of different water delivery systems, (i.e. backpack reservoir drinking systems vs. traditional canteens) to see how they may alter drinking

behavior. The accessibility and ease of usage could play a role in the frequency and volume of water consumed. However, it is also strongly advised that individuals receive some type of feedback that allows them to quantify hourly consumption patterns. This would more likely ensure adequate intake while limiting excessive or inadequate intake of fluids during arduous work.

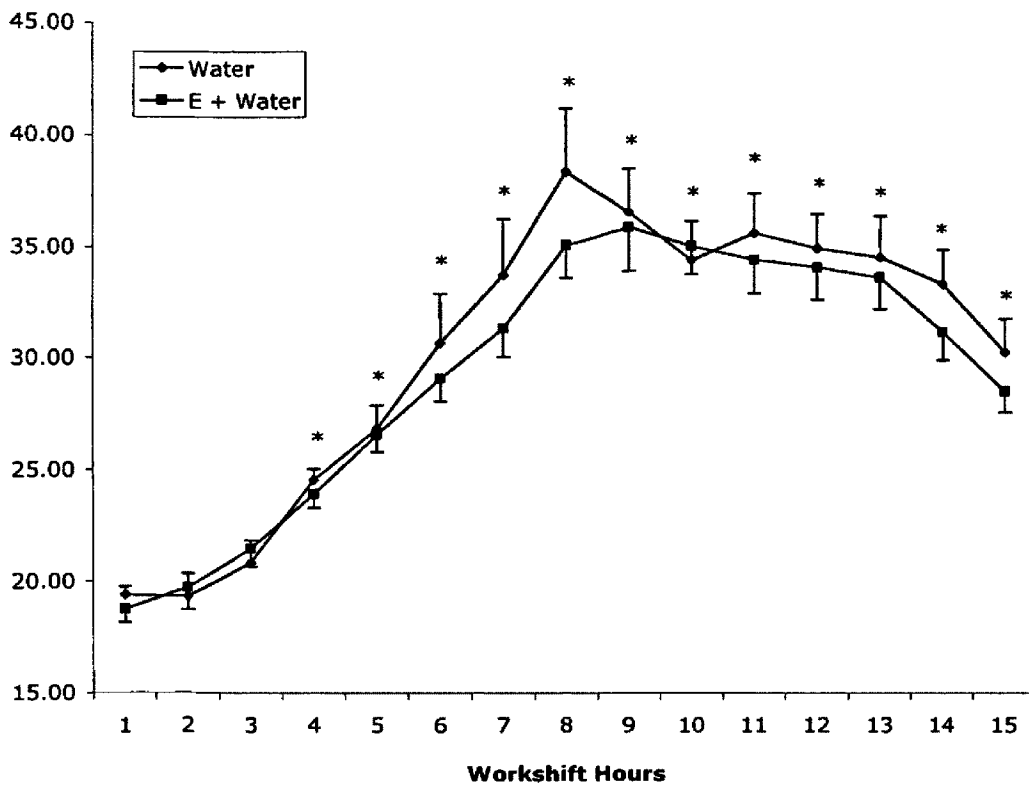


Figure 1. Changes in ambient temperature (°C) during the workshift. * $p < 0.05$ main effect for time indicating that the average values for hours 4-15 were significantly higher compared to hour 1.

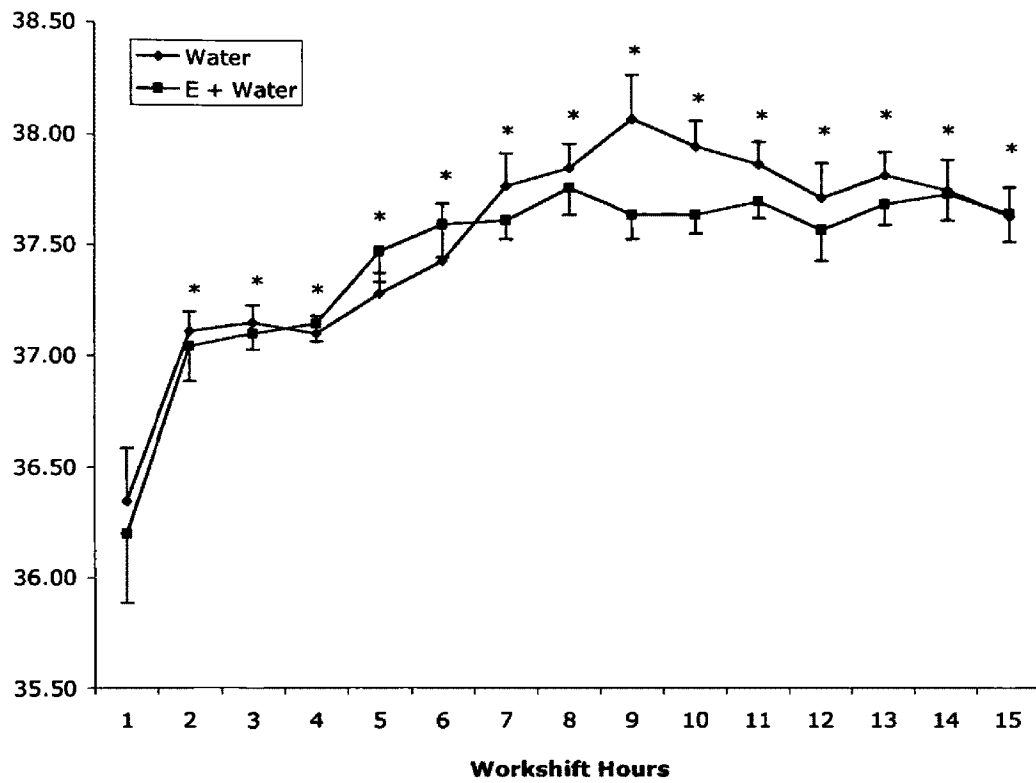


Figure 2. Changes in core temperature (°C) during the workshift. * $p < 0.05$ main effect for time indicating that the average values for hours 2-15 were significantly higher compared to hour 1.

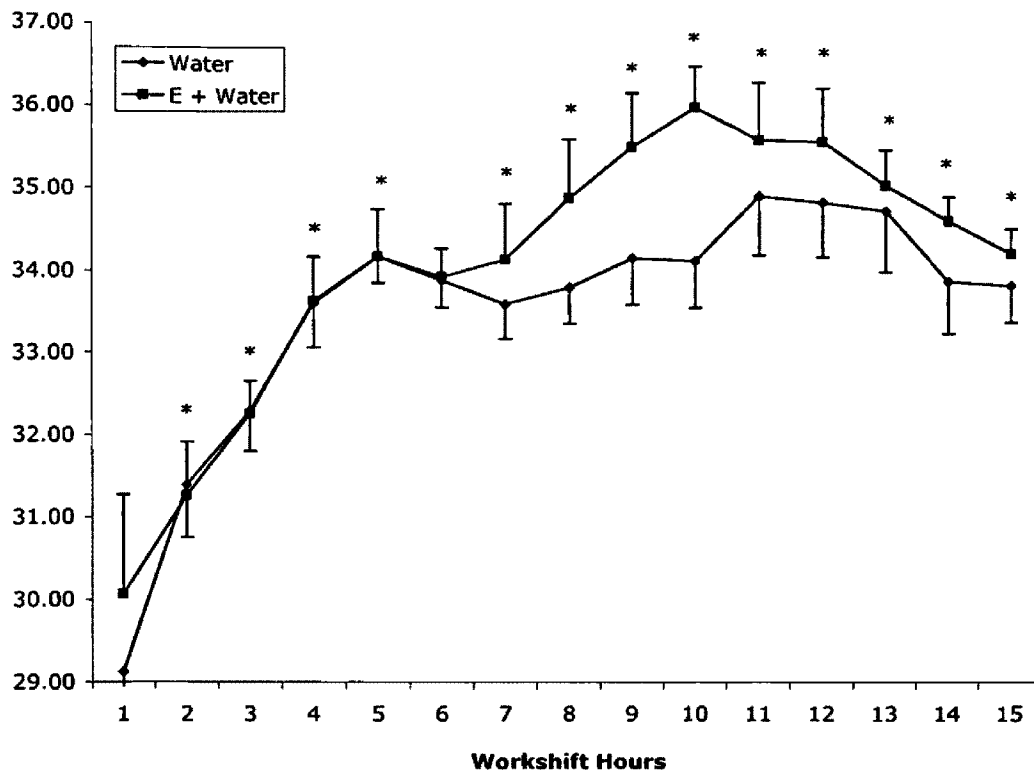


Figure 3. Changes in skin (lateral left deltoid) temperature (°C) during the workshift.

* $p < 0.05$ main effect for time indicating that the average values for hours 2-15 were significantly higher compared to hour 1.

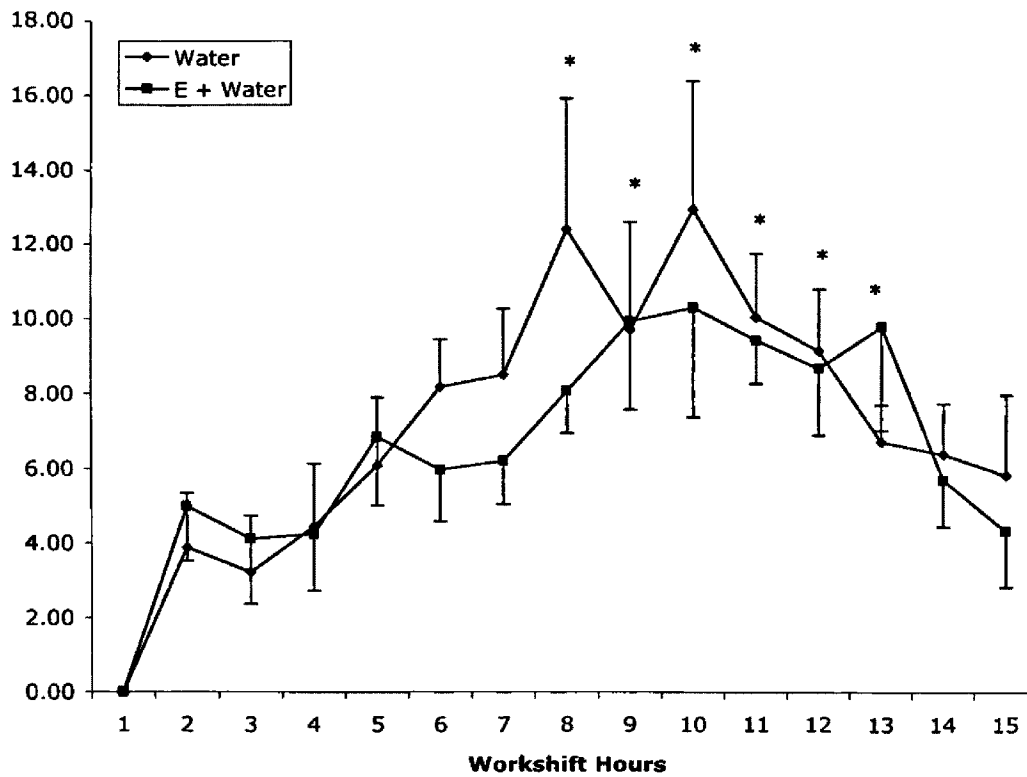


Figure 4. Changes in hourly drinking frequency (drinks·hour⁻¹) during the workshift.

p<0.05 main effect for time indicating that the average values for hours 8-13 were significantly higher compared to hour 2.

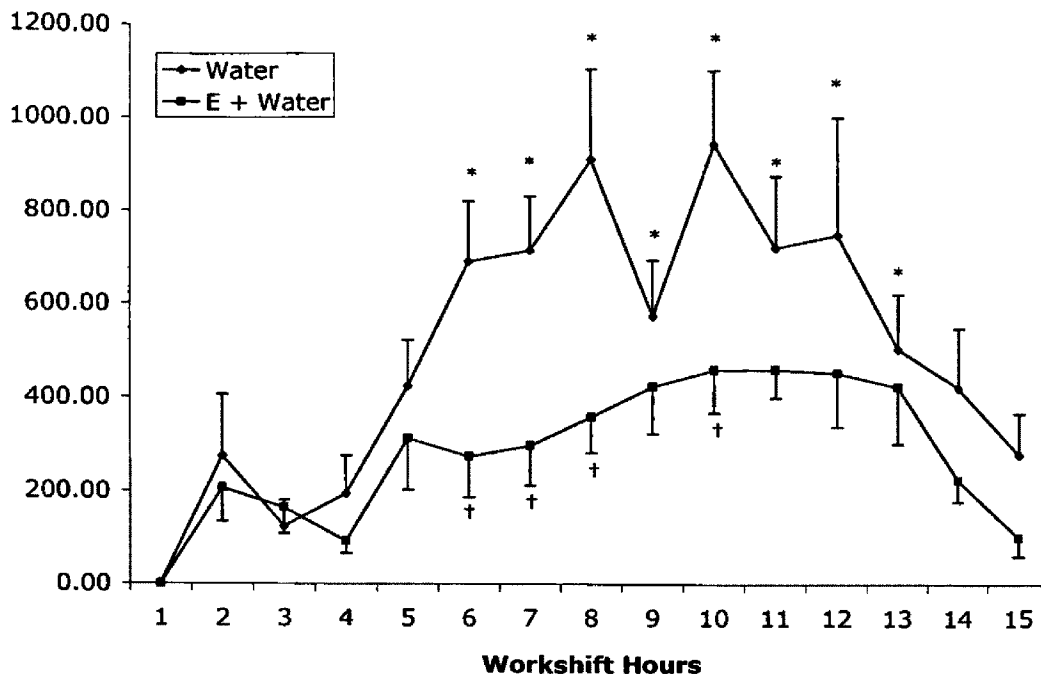


Figure 5. Changes in hourly drinking volume (ml) during the workshift. * $p < 0.05$ main effect for time indicating that the average values for hours 6-13 were significantly higher compared to hour 1, whereas hours 2-5 and 14-15 were not significantly different from hour 1.

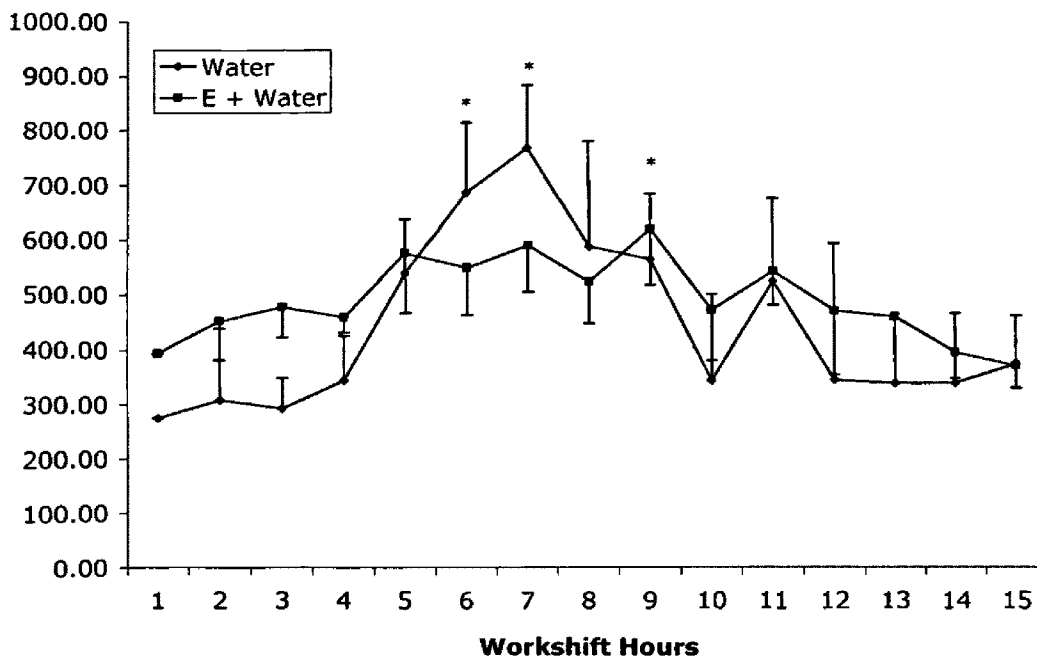


Figure 6. Variations in activity monitor counts (average hourly counts) during the

workshift. * $p < 0.05$ main effect for time indicating that the average values for hours 6-13 were significant higher compared to hour 2.

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

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

Table 2. Changes in Body Weight

	AM	PM
Water	81.77 \pm 16.54	81.35 \pm 16.35
Water + E	78.02 \pm 11.51	77.06 \pm 11.87
Average	79.79 \pm 14.10	79.09 \pm 14.21

Table 3. Urine Osmolaity

	AM	PM
Water	1.019 \pm 0.007	1.019 \pm 0.005
Water + E	1.022 \pm 0.011	1.025 \pm 0.008
Average	1.019 \pm 0.005 *	1.023 \pm 0.009 *

* $p < 0.05$ main effect for time

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References

- Almond, C. Shin, A., Fortescue, E. Mannix, R., Wypij, D., Binstadt, B., Duncan, C., Olson, D., Salerno, A., Newburger, J., Greenes, D. (2005) Hyponatremia among Runners in the Boston Marathon. *New England Journal of Medicine* **352** (1), 1550-1556.
- Armstrong, L.E., Y. Epstein. (1999) Fluid-electrolyte balance during labor and exercise: concepts and misconceptions. *Int J Sports Nutr* **9** (1), 1-12.
- Fusch, C. W. Gfrorer, C. Koch, A. Thomas, A. Grunert, and H. Moeller (1996) Physical fitness influences water turnover and body water changes during trekking. *Med. Sci. Sports Exerc.* **35**, 704-708.
- Latzka, W.A. and S.J. Montain, (1999). Water and electrolyte requirements for exercise *Clin Sports Med.* **18**, 513-524.
- Maughan, R.J., J.B. Leiper, S.M. Shirreffs (1997) Factors influencing the restoration of fluid and electrolytes balance after exercise in the heat. *Br J Sports Med* **3**,175-82.
- MiniMitter Respironics, Bend, Oregon.
- Ruby, B.C, D.A. Schoeller, and B.J. Sharkey (2002) Evaluation of total energy expenditure (doubly labeled water) across different measurement periods during arduous work *Med Sci. Sports Exerc.* **34**, 1048-1054.

Ruby, B.C, D.A. Schoeller, B.J. Sharkey, C. Burks, and S. Tysk (2003) Water turnover and changes in body composition during arduous wildfire suppression *Med. Sci Sports Exerc.* **35**, 1760-1765.

Sawka, M.N., S.J. Montain and W.A. Latzka (2001) Hydration effects on thermoregulation and performance in the heat *Comparative Biochemistry and Physiology* **128**:(4) 670-90.