Assessing the Effects of Energy Drinks upon Firefighter Health and Safety

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Certification Statement

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Abstract

Prior research on the health effects of energy beverages (EBs) as well as caffeinated beverages has been contradictory and therefore inconclusive. As a result of their purported health risks the use of EBs within the fire service has been called into question. The current problem has been that many firefighters continue to consume EBs at or before work, but the use of such drinks may contribute to dehydration or cardiac arrhythmias, and/or increase cardiac workload to dangerous levels.

The purpose of this study was to determine if the use of EBs creates a potentially dangerous level of dehydration or cardiac workload to firefighters or increases the incidence of cardiac arrhythmias. A double-blind crossover experimental research method was utilized to test our hypotheses that EB consumption poses significant health risks to firefighters because elevated levels of caffeine and sugar: (a) exacerbate dehydration (H_1), and (b) increase cardiac stress (H_2).

In order to assess the health effects of EBs, a cohort of 23 firefighters was randomly selected to participate in a double-blind crossover study that measured cardiac and hydration effects of both an EB and a placebo beverage (PB) over a 3 hour period, which included a 30 minute exercise routine that mirrors the National Wildfire Coordinating Group (NWCG) "pack test." Assessment consisted of measurement of cardiac related vital signs, urinary output, and cellular hydration via bioimpedance analysis (BIA). Results revealed significant decreases in intracellular hydration immediately post exercise, as well as increased urinary output, blood pressure, and heart rate when EBs were consumed. At the end of our study, we found that given the nature of firefighting, it is recommended that firefighters limit their consumption of EBs and

hydrate regularly. Future research should evaluate the long-term effects of EBs under sustained firefighting conditions.

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Introduction

The insurgence of energy beverages (EBs) has spiked both their popularity and controversy, offering the purported benefits of increased alertness and energy on the one hand and potentially significant health risks on the other. While firefighters have a need to possess both mental and physical stamina, which EBs have been reported to deliver, the synergistic effect of their ingredients has been alleged to produce untoward cardiac and dehydrating effects. Cardiac stress, dehydration and diuresis (increased fluid loss through urination) are undesirable in a work environment that inherently exacerbates these conditions. The use of EBs within the fire service has been called into question, particularly within the wildland firefighting community for these reasons. Prior research on the health effects of caffeinated beverages is contradictory and therefore somewhat inconclusive and scant research exists relevant to the consumption of EBs in conjunction with physical exertion.

The current problem has been that many firefighters continue to consume EBs at or before work, and the use of such drinks is believed to contribute to dehydration and/or cardiac arrhythmias, and/or increase cardiac workload to dangerous levels. When increased workload demands are encountered moreover, such as at campaign wildfires, firefighters seek to enhance their endurance and/or alertness by increasing their consumption of caffeinated beverages in general and EBs in particular, thereby potentially exacerbating their health risks. Heat related injuries resulting from dehydration are among the most common injuries encountered at wildfires (Heat Illness Working Group, 2009) and include severe health emergencies such as heat stroke and rhabdomyolysis (muscle tissue damage leading to kidney failure), and cardiac related events are the primary cause of firefighter line of duty deaths (USFA, 2002).

The North County Fire Protection District (NCFPD) has recently initiated a firefighter health and wellness program in conjunction with Santa Ana Community College. This program takes a holistic approach to health and fitness and encompasses physical assessment, exercise and nutrition counseling, and periodic monitoring. Given the need for prolonged physical endurance demanded in wildland firefighting, this program emphasizes cardiovascular fitness. Being situated in Southern California this agency has either responded to or directly experienced multiple wildfires each year and will continue to do so for the foreseeable future, meaning that our personnel are routinely expected to perform in hot, dry, arduous working conditions for long periods of time. Recent research from the Orange County Fire Authority (Boyle, 2008), as well as from the Heat Illness Working Group (2009) emphasize the critical relationship between adequate hydration, cardiovascular fitness, and avoidance of unnecessary cardiac stress.

Previous research based on the association of EBs with dehydration and cardiac stress gave rise to the need of studying the effects of EBs further. The purpose of this study was to determine if the use of EBs is associated with a potentially dangerous level of dehydration or cardiac workload to firefighters or increases the incidence of cardiac arrhythmias. A double-blind crossover experimental research method was utilized to test our hypotheses that EB consumption poses significant health risks to firefighters because elevated levels of caffeine and sugar: (a) exacerbate dehydration (H_1), and (b) increase cardiac stress (H_2). This research aimed to either support or reject the null hypothesis, that there is no significant difference in either hydration levels or cardiac workload in firefighters when consuming EBs (H_0).

Background and Significance

The region served by the NCFPD is a semi-rural bedroom community located in northern San Diego county, which consists of approximately 100 square miles of territory situated in chaparral covered hilly terrain. Within the past decade this community has experienced two catastrophic wildfires (Gavilan Fire, 2002 and Rice Fire, 2007), and as a member of the California State Master Mutual Aid System regularly responds to numerous campaign wildfires each year. As a result our personnel are regularly exposed to firefighting conditions in hot, dry environments for extended periods of time. Under these conditions food, water, and shelter can become scarce, particularly when working thousands of feet from the nearest apparatus or inhabited structure. As a result heat injury is not uncommon at such incidents, even with proper nutrition, rest, and hydration. While various rehabilitation policies exist they are geared toward structural firefighting and do not take into account the unique conditions present during wildland firefighting.

It is therefore evident that adequate rest and hydration are critical in order to maintain firefighter health and safety, and consumption of any substance that could potentially detract from this would seem counterintuitive. Notwithstanding, in order to maintain alertness and/or physical stamina many firefighters will consume EBs, particularly when they lack proper rest, hydration and nutrition. It is not at all uncommon for firefighters to stay awake all night, driving to an incident as part of a strike team assignment, only to arrive at an incident and go directly to work for 12-24 hours or longer.

Given the combination of wildland firefighting and the proliferation of EBs, it is no surprise that the controversy surrounding EBs has grown within the fire service in general and NCFPD in particular. With regard to their popularity, from 2004-2009 the volume of EB sales has grown 240%, and the overall U.S. EB market is expected to double by 2013 (Heckman, Sherry, & Gonzalez De Mejia, 2010, p. 2). Young adults ages 18-34 years old are the targeted demographic audience (Lal, 2007), an age group that comprises a significant proportion of our firefighting ranks. Notwithstanding, regionally incident management teams (IMTs) have intermittently begun to recommend avoidance of EBs while at campaign wildfire incidents; the author has had personal experience with this occurrence during the 2009 Southern California wildfires. The Heat Issues Working Group (2009)—which is comprised of medical directors and fire officials from Southern California—has produced a report which includes avoidance of EBs as a method of reducing heat injury during wildland firefighting. Due to the perceived diuretic and cardiac effects associated with EBs, within our department employees have been directed to avoid EB consumption prior to stress electrocardiogram (ECG) evaluation (T. Wann, personal communication, November 20, 2010) and in some cases directed by their supervisors to avoid EBs entirely while on duty.

In addition to reducing heat injury during wildland firefighting, we believe that EBs should be avoided for other health reasons, including their cardiovascular effects. Unfortunately, there is conflicting research on the subject which leads to inconclusive evidence about the negative health impact of EBs. For example, in some studies moderate doses of caffeine (100-240 mg) have been shown to have diuretic (Bichler, Swenson, & Harris, 2006) as well as cardiovascular effects (Riesenhuber, Boehm, Pausch, & Aufricht, 2006), while others found no adverse health effects due to the consumption of caffeine (Ryan, 2007), a combination of taurine, ginseng, or guarana at levels typically found in mainstream EBs (Clauson, Shields, McQueen, & Persad, 2008), or a greater risk of heart disease when compared to a control group (Diederick et al., 1990; Lopez-Garcia et al., 2006). Incidental cases of severe cardiac arrhythmias (Nagajothi et al., 2008) and even cardiac arrest (Cannon, Cooke & McCarthy, 2001) have been reported to be associated with EB consumption, although in such cases excess amounts were consumed and/or were consumed by persons with underlying cardiac diseases (Cannon, Cooke, & McCarthy, 2001; Duchan, Patel, & Feucht, 2010).

Such beverages are perceived to pose a significant health concern because of the relationship between their ingredients and known health risks. For example, prior research has illustrated the risks between dehydration and heart attack (Chan, Knutsen, Blix, Lee, & Fraser, 2002) and stroke (Rodriguez et al., 2008). Caffeine is a known diuretic that results in water elimination at a rate of 1.17ml/ mg of caffeine (Stookey, 1999). The link between dehydration and hyperthermia has shown that collectively they result in cardiovascular instability that puts individuals at risk for heat exhaustion (Ganio, Casa, Armstrong, & Maresh, 2007). Still others postulate that heat stroke may be the result of failure of internal heat loss mechanisms perhaps precipitated by caffeine rather than a combination of excessive heat and dehydration per se (Tucker & Dugas, 2008). Caffeine has been associated with malignant hyperthermia (MH) and has been used to diagnose this condition (Hopkins, 2000). Dehydration and caffeine have been identified as contributing factors to the onset rhabdomyolosis among firefighters during wildfire assignments (CDC, 2010). Consumption of simple sugars spikes serum insulin levels and increases one's risk of diabetes (Wolever & Miller, 1995) as well as cardiovascular disease and death (Esposito et al., 2002). Alarmingly, EB consumption has been shown to be positively associated with high-risk behavior, including marijuana use, sexual risk taking, fighting, failure to use seat belts, taking risks on a dare, smoking, drinking, problems stemming from alcohol abuse, and illicit drug use (Higgins, Tuttle & Higgins, 2010). Moreover, EBs supply an amount of carbohydrates two to three times that recommended for physically active people (Clauson et al., 2008) which can slow the rate at which fluid is absorbed into the bloodstream or lead to gastrointestinal distress including vomiting (Davis, Burgess, Slentz, Bartoli, & Pate, 1988; Casa, Armstrong, Montain, Rich, Stone, 2000).

Clearly dehydration is undesirable during strenuous physical activity, and there are several contributing factors that exacerbate this condition. To begin, according to the 1977-1978 Nationwide Food Consumption Survey Americans consume 500-1000 ml less than recommended levels (USDA, 1984). This chronic dehydration is supported by Boyle (2008), who illustrated that 64% of firefighters were mildly dehydrated and of those, 26% were moderately dehydrated. Our bodies do not necessarily detect thirst until we are already dehydrated to a level of .8% to 2% of body weight (Sagawa et al., 1992), which could partially explain this pervasive chronic dehydration. Moreover, if dehydration levels exceed 3% electrolyte and nutrient supplementation is required to restore normal hydration levels, which may take up to 24 hours to achieve (Sagawa et al., 1992). Considering the well documented association between firefighting and cardiac stress, that 44% of firefighters die annually from heart attacks, and overexertion/strain represents 46% of all fatalities (USFA 2002), it is presumable that exacerbation of dehydration in firefighters is undesirable if not dangerous. Based upon the *Adventist Health Study* (Chan et al., 2002), there is a negative correlation between increased water intake levels and risk of a fatal cardiovascular event, and a positive association with regular consumption of elevated quantities of “high energy” beverages. While not a direct comparison of water versus energy drinks for hydration, intuitively the implication is that the increase in consumption of EBs is associated with an increased risk of suffering a fatal cardiovascular event.

Notwithstanding, caffeinated products have demonstrated enhanced athletic performance, with peak effects ranging from 60-90 minutes after consumption (Smit, Cotton, Hughes, &

Rogers, 2004; Ganio, Klau, Casa, Armstrong, & Maresh, 2009), and a moderate intake (1.4-2.7 mg/kg) will not compromise daily hydration status (Ryan, 2007). EBs were similarly shown to increase time to exhaustion and maximum oxygen consumption without negatively affecting heart rate (Rahnama, Gaeini, & Kazemi, 2010). Similarly, EBs were found to enhance mood and cognitive functions when compared to a placebo (Smit et al., 2004) as well as attention and memory recall (Scholey & Kennedy, 2004). The November 2010 edition of the *Mayo Clinic Proceedings* notes:

> The human body develops a tolerance to caffeine quickly, usually 3 to 5 days after regular use, and when this happens, it noticeably weakens the already limited diuretic effect of caffeine. Moreover, the human kidneys are masters at ensuring that proper homeostatic conditions are maintained. Recent research now leans toward the ability of the body to maintain proper water levels and overcome the mild diuretic effects of caffeine in long-term users (Higgins, Tuttle & Higgins, 2010, p. 1039).

Considering the aforementioned, it is evident that prior research pertaining to caffeinated beverages is contradictory and therefore inconclusive, and present research on EBs has evaluated subjects at rest or has analyzed their various contents individually (most notably caffeine), rather than the net cardiovascular and diuretic effects when exercise is involved. The main active ingredient in EBs is caffeine, although other substances such as taurine, guarana, ginseng, yerba mate, riboflavin, pyridoxine, nicotinamide, other B vitamins, and various herbal derivatives are also present (Reissig, 2009). Heneman and Zidenberg-Cherr (2007) note that the caffeine content of a single serving of EB (8 to 12 fl oz) can range from 72 to 150 mg however, many cans contain 2-3 servings, raising caffeine content to nearly 300 mg per container. In comparison, the caffeine content per serving (8 fl oz.) of brewed coffee, tea, and cola beverages ranges between 134-240 mg, 48-175 mg, and 22-46 mg respectively. Table 1 below illustrates the caffeine and sugar content of EBs.

Table 1

Caffeine and Sugar Content of Energy Drinks

Drink	Serving (fl. Oz.)	Servings per Container	Sugar per serving (g)	Caffeine per serving (mg)	Kcal
Diet Rockstar Energy Drink	8	2	0g	80	10
Full Throttle	8	2	29g	72	111
Go Girl Sugar Free	12	1	0g	150	3
Lo-Carb Monster XXL	8	3	3g	80	10
Monster Energy Assault	8	2	27g	80	100
Monster Energy XXL	8	3	27g	80	100
Red Bull Sugar Free	8.3	1	0g	80	10
Red Bull	8.3	1	27g	80	110
Rockstar Energy Drink	8	2	30g	80	130
Rockstar Juiced	8	2	21g	80	90
Wired 294 Caffeine	8	2	26g	147	100

Note: From Heneman and Zidenberg-Cherr, 2007, p. 3.

Given this background this research focuses on the health impacts of high sugar and caffeine containing beverages, particularly as they relate to hydration and cardiac stress. As this study analyzes firefighters' physiologic response to EBs, it will serve to address a contemporary firefighter health and safety issue, particularly within the wildland firefighting community where it is receiving the greatest attention. There is a direct correlation to the logistical support considerations discussed in the National Fire Academy's Executive Analysis of Fire Service Operations in Emergency Management (EAFSOEM) curriculum because this matter has arisen out of Type 1 and Type 2 campaign fires that engender conditions hazardous to responder health and safety. Because NCFPD regularly responds to such campaign incidents that demand optimal physical performance of one's duties, having a clear understanding of the proper utilization of EBs (or any substance that can significantly affect performance) is paramount. Inasmuch as EBs are only expected to proliferate and both their use and misuse has received substantial media attention as well as attention within this organization, the findings from this study will address a growing contemporary health and safety issue for our personnel. Finally, because there are both positive and negative effects associated with EB consumption that can affect firefighter performance and health, this research will ideally provide further balanced guidance to NCFPD personnel regarding their use and limitations. To this end this research supports two of the United States Fire Administration's (USFA) current strategic goals, namely: (a) to improve the fire and emergency services' professional status and, (b) lead the Nation's fire and emergency services by establishing and sustaining USFA as a dynamic organization.

Literature Review

The popularity of caffeinated beverages and hydration as it relates to sports nutrition has generated a substantial amount of literature germane to those subjects, and the more recent controversy surrounding EBs in combination with alcohol has likewise produced several studies. However, there is scant scholarly literature that directly pertains to the health effects of EBs, particularly in combination with physical exertion. Resultantly, this literature review covers a composite of the health effects of the ingredients of EBs as well as EBs themselves. Moreover, as the specific purpose of this study is to evaluate the cardiac and hydration effects of EBs, literature relevant to these topics is also included.

Although substantial research exists relevant to the short-term cardiovascular effects of caffeine, which would presumably increase the risk of cardiovascular disease, little research existed which evaluated if a tolerance is developed with ongoing consumption, thereby mitigating some of these acute effects. Robertson, Wade, Workman, Woosley, and Oates (1981) evaluate 18 subjects for a 14 day period, prior to which they refrained from consumption of any caffeinated foods or beverages as well as from any drugs. During the study period subjects were given either a caffeinated drink containing 250 mg of caffeine or a placebo (decaffeinated coffee substitute) three times a day. Serum caffeine and catecholamine levels (epinephrine and norepinephrine) were periodically obtained, and blood pressure and heart rate were routinely measured. Mean systolic blood pressure was significantly elevated (11.2 mmHg.) within 2 hours of initial caffeinated beverage consumption and remained elevated for the first 2 days of the study, but by day 4 blood pressure levels had returned to near baseline and remained there for the remainder of the study period. There was no significant effect upon heart rate when compared to the placebo group. During this same time frame serum catecholamine levels remained elevated for 3-4 hours post caffeine consumption, but by the end of the study there was no effect of caffeine upon serum catecholamine levels. Subjects with the lowest serum caffeine levels showed the greatest increase in systolic blood pressure changes.

Based upon findings from the Nationwide Food Consumption Surveys (USDA, 1984), which revealed that a significant number of Americans are chronically mildly dehydrated, Kleiner (1999) evaluates current methods of hydration and makes various recommendations. It is revealed that water loss of as little as 2% in body weight leads to impaired cognitive and physical performance, and long-term dehydration leads to a range of chronic if not fatal illnesses including cancers, renal system disorders, and various heart conditions. The author recommends that women consume a minimum of 2200 ml of fluid daily and men consume 2900 ml, in the form of non-caffeinated, non-alcoholic beverages. Increased fluid replacement is recommended for athletes, recommending 500 ml of water (approximately 16 oz) 1-2 hours before exercise, 4-8 ounces of water for each 15-20 minutes during exercise, and 16-20 ounces for each pound lost during exercise.

During a panel discussion at the 2000 National Athletic Trainer’s Association conference, Casa, Armstrong, Montain, Rich, and Stone (2000) provide a number of recommendations regarding hydration, monitoring, and environmental controls relevant to athletic training. Changes in circulating fluid volume and electrolyte levels are associated with altered thermoregulation (body temperature regulation) and cardiovascular response. It is noted that every 1% decrease in weight from fluid loss increases resting heart rate by 3-5 beats per minute and that dehydration decreases motivation and time to exhaustion. Hot environments are noted to exacerbate both of these conditions. Performance begins to be affected when dehydration exceeds 1-2% of body weight and therefore hydration strategies should be developed that maintain hydration above this level. This should include pre-hydration with 500-600 ml of water or a sports drink and consumption of 200-300 ml of fluid for every 10-20 minutes of exercise. Athletes were advised to avoid caffeinated drinks due to increased urine production and decreased fluid retention. Beverages containing carbohydrates greater than 8% were to be similarly avoided due to their tendency to slow gastric emptying and intestinal absorption. Athletes that transition from a cool to a hot environment will experience increased sweat rates during physical demands, thereby leading to hyponatremia (low sodium), and therefore require rehydration with beverages containing sodium. It is noted that it takes athletes 5-10 days to physiologically acclimatize to hot conditions.

The United States Fire Administration (2002) conducted a long-range retrospective analysis of firefighter fatalities, analyzing all fire service fatalities between 1977 and 2000. This analysis provided a comprehensive review of the nature of all firefighter fatalities; for purposes of this research review of this literature focuses on cardiac related events. The study revealed that while the rate of firefighter deaths has steadily declined during the study period, a significant proportion of these fatalities were precipitated by overexertion/strain (46%), and 43.9% of all fatalities were the result of a heart attack. More strikingly, medical causes represent nearly 50%

of all fatalities for firefighters over the age of 40 and this rate increases nearly 10% for each subsequent 5 year increment (USFA, 2002, p. 19). Not surprisingly, firefighters over the age of 50 are "killed in the line of duty at a rate disproportionate to their representation in the fire service" (USFA, 2002, p. 2). Overall a firefighter's risk of death from a heart attack is roughly double that of other professions that experience substantial down-time followed by periods of significant physical exertion, and roughly triple that of all professions (USFA, 2002, p. 26). Among firefighters, the leading precipitating causes of their heart attacks were arteriosclerosis, prior heart attacks, and hypertension (USFA, 2002, p. 24).

Given the association between hydration, blood viscosity and heart disease, Chan, Knutsen, Blix, Lee, and Fraser (2002) studied the incidence of a large cohort of Seventh Day Adventists to determine if there was indeed an association between types of hydration and the risk of suffering a fatal cardiovascular event (heart attack, stroke, or pulmonary embolus). This cohort was selected given their relative consumption of water, juice, and milk relative to known diuretics such as alcohol, regular sodas, and caffeinated beverages. A detailed lifestyle analysis was completed for each of the cohort participants, who were followed for a 6-year period. Their findings revealed that there is a negative association between water intake levels and risk of cardiovascular disease, with those that regularly consume higher quantities of water (5 or more 8 ounce glasses) roughly 50% less likely (46% for men and 59% for women) of suffering a fatal coronary heart disease event. Moreover, those who disproportionately consumed low volumes of water (2 or fewer glasses per day) and higher volumes (5 or more glasses per day) of "high energy" drinks such as juices, caffeinated sodas, etc., were approximately 1.5 times (men) to 2.5 times (women) more likely to suffer a fatal cardiac event. The authors point to various physiological factors that lead to elevated blood viscosity (thickness) and a higher incidence of heart attack, particularly during the morning hours. They also point to the significant impact consumption of high energy drinks has upon elevating triglyceride levels (50% increase) and the association between triglycerides and heart disease. Relative water intake is suggested by the authors to be a probable coronary risk factor and deserving of future study.

Due to the ongoing controversy surrounding inconsistencies in research regarding the relationship between coffee consumption and coronary heart disease (CHD), Lopez-Garcia et al. (2006) examined 2 large cohorts over a long duration (44,000 men over 14 years and 84,400 women over 20 years) to determine the long-term effects of coffee upon CHD. The study also examined if there was a causal relationship between other mitigating risk factors including diabetes, obesity, smoking, or alcohol consumption. Persons with known CHD were excluded from the study. Given the size of the 2 cohorts adjustments were made for a number of known mitigating factors, including the type of coffee consumed (regular versus decaffeinated) as well as method of filtration, use of aspirin and vitamins, high cholesterol and hypertension, physical activity, and hormone therapy. Results revealed no short or long-term association between total caffeine intake and CHD in men or women.

Riesenhuber, Boehm, Pausch, and Aufricht (2006) evaluate the diuretic potential of EBs by having 12 young healthy males who were moderate caffeine consumers ingest each of four different test drinks over a four-week period. The drinks contained simply water, water and taurine, water and caffeine, or water, caffeine, and taurine. Concentrations of the ingredients were comparable to that found in a Red Bull energy drink (80 mg caffeine and 1 g taurine per 250 ml). Each test drink was 750 ml, or the equivalent of drinking the volume of 3 Red Bull energy drinks. The participants were asked to refrain from alcohol 48 hours prior to the test and fast for 12 hours prior to testing. Results revealed that urinary output and natriuresis (urinary sodium excretion) increased with caffeine containing test drinks but not with drinks containing only taurine, and drinks with both caffeine and taurine produced similar results to the caffeine only drinks. There were no differences in body weight, blood pressure, or changes of body composition by bioimpedance between the 4 treatments. The authors conclude that the diuretic effects of EBs are moderated by caffeine alone.

Ganio, Casa, Armstrong, and Maresh (2007) evaluate present literature that assesses the physiologic effects of the various common ingredients found in both EBs and sports drinks. As has been shown in previous studies, the authors confirm that there is a direct correlation to adequate hydration and heat injury and that core temperature increases more rapidly in dehydrated individuals. In exploring a number of studies on caffeine, they conclude that while moderate caffeine intake (1.4 – 3.1 mg/kg) has a mild short-term diuretic effect (<3 hours), over a 24 hour period or greater there is no long-term effect. Only large amounts of caffeine (8.2 – 10.2 mg/kg) ingested over 24 hours produced substantive changes in hydration status, however the authors suspected that the renal fluid regulating mechanisms mitigated short-term increases in urine output. Similarly, caffeine consumption prior to exercise was not shown to increase urine output, which is attributed to increased catecholamine presence and resultant reduced renal blood flow. They conclude that consumption up to 300-400 mg of caffeine daily does not significantly alter either core body temperature or hydration status. Because some hypothesize that metabolic rate may influence some studies, the authors call for further randomized crossover experiments that evaluate both exercise intensity rate and hydration status.

In 2008 the Federal Institute for Risk Assessment (BfR) in Germany conducted a review of current research and international policy pertaining to energy drinks. Their review not only reaffirms their support of current warning labels but also supports additional labeling. This is based upon findings from a number of human studies that demonstrate cardiac effects associated with caffeinated beverages as well as EBs. In particular, they recommend caution in consuming such beverages in persons with cardiovascular disease, hypertension, or in conjunction with intensive physical activity, as well as while pregnant or in conjunction with alcoholic beverages. A maximum daily intake of 200 mg of caffeine was also recommended. While there was speculation as to the synergistic effects of taurine and other additives, further research evaluating the cumulative effects was recommended, particularly when consumed during physical activity or in conjunction with alcoholic beverages.

In order to determine the prevalence and relative risk of EBs to U.S. Air Force personnel, Schmidt, McIntire, Caldwell, and Hallman (2008) surveyed 377 active duty personnel regarding their consumption. This cohort represented a wide range of ranks with a median tenure of 9 years in the military. Participants were asked to evaluate their rate of consumption as well as enumerate the perceived benefits and side effects associated with their EB consumption. Respondents were found to be substantially more likely to consume EBs on a daily basis when compared to the American college students (30% versus 22% respectively) and cited increased mental alertness (77%) as the most common desired benefit, followed by increased mental endurance (39%) and physical endurance (35%). Several negative side effects were also noted, including increased heart rate (31%), insomnia (31%), dehydration (21%), nervousness (11%), and trouble staying asleep (11%) as being the most prevalent. The authors express concern over the popularity of continued EB consumption despite their reported negative side effects, and suggest alternative strategies to meet the demands for increased mental alertness and physical endurance.

A study of firefighter hydration and body core temperatures was conducted by Boyle (2008) in order to determine appropriate hydration and cooling procedures. With regard to hydration, the research emphasized that dehydration is a risk factor for heat injury and cardiovascular events, and that fluids lost through sweat must be replaced to prevent excessive dehydration and excessive changes in electrolyte balance. Of the study participants a significant proportion (65%) were at least minimally dehydrated and of these 26% were moderately to seriously dehydrated. 58% of the study participants lost between 2-3% of their body weight through sweat during 30 minutes of physical exertion. For those performing simulated firefighting activities the average heart rate was 190 beats per minute and several participants exceeded their 100% maximum heart rate. For this reason, added stimulus to the heart was noted to be undesirable. A variety of cooling methods were recommended, as was rehydration via consumption of sports drinks that contain glucose and sodium rather than water alone, particularly for larger volumes of fluid loss through sweating.

While of a different mechanism than heat related emergencies per se (heat exhaustion and heat stroke), malignant hyperthermia (MH) is a condition of hypermetabolism (runaway cellular metabolism) that is typically associated with untoward medication reactions, to include caffeine. Tucker and Dugas (2008) review 18 documented cases of heat stroke wherein, based upon the climatic conditions presented, in each case the victims experienced “a potential for heat loss that exceeded the amount of heat they would produce from exercise” (p. 3). Two of the cases involved healthy runners that experienced fully developed heat stroke after 16 minutes of running in temperatures between 62-72 ºF. It is noted that certain individuals are predisposed to MH, which occurs through stimulating an increase in intracellular calcium, which in turn increases metabolism and core body temperature. Furthermore, agents that stimulate the sympathetic nervous system such as caffeine are known to have similar effects upon calcium channels. The authors conclude that heat stroke is perhaps a physiologic failure similar or related to MH rather than the result of environmental conditions per se.

Clauson, Shields, McQueen and Persad (2008) reviewed current literature to evaluate the efficacy and potential risks associated with the various ingredients included in energy drinks. Of particular note the authors evaluate bitter orange which, while not common ingredient in EBs has a mechanism of action similar to ephedra, the key active ingredient in methamphetamine. While concentrations exist in dosages below a therapeutic effect, typically 200 mg, the authors raise concern regarding the synergistic effect with caffeine and guarana. Collectively their research illustrates that the quantities of guarana, taurine, and ginseng contained in EBs are insufficient to produce either health risks or nutritional benefits. However, they note the typical sugar content of many EBs is 2 to 3 times that recommended and therefore raise concern regarding sustained consumption and the potential long risk of obesity and diabetes, both of which have been linked to excessive sugar consumption. Although the incidence of significant serious health consequences is relatively rare, the authors raise concern that many less serious events may go unreported because the Dietary Supplement and Nonprescription Drug Consumer Protection Act only requires the reporting of serious health events (inpatient hospitalization or death). Consequently, they recommend that groups susceptible to the effects of elevated levels of sugar or caffeine consult their physician prior to consuming EBs and raise concern over athletes that consume EBs prior to strenuous physical exercise.

Reissig, Strain, and Griffiths (2009) study the increasing popularity of EBs and explore the range of documented health and behavioral side effects associated with them. They express concern over the synergistic effect of their contents which may exacerbate the stimulant effects of simple caffeinated drinks (e.g. coffee). Largely unregulated in the U.S. and specifically targeted to young adult males, they note a rise in reported cases of caffeine intoxication and even death resulting from energy drink consumption. While acknowledging the potential benefits commonly associated with mild to moderate caffeine consumption, they shed doubt on the overall benefit when taking caffeine withdrawal into account. Moreover, they cite a positive association of caffeine use with dependency upon alcohol, nicotine, and stimulants, suggesting that further research may be warranted to determine if caffeinated substances serve as a gateway drug.

In order to determine the effects of caffeine during exercise in a hot environment, as well as the mechanisms by which caffeine may alter physical condition, Del Coso, Estevez, and Mora-Rodriguez (2009) test seven acclimatized cyclists in a hot, dry environment. Study participants consumed either water or a simulated sports drink, both with and without a moderate dose of caffeine (6mg/kg), and were then asked to cycle for 120 minutes. Predictably, core body temperatures showed a significant increase when participants were not given fluids prior to exercise. Caffeinated drinks revealed no significant change in heat dissipation or sweat rate when compared to non-caffeinated drinks. A notable increase in urine output and loss of electrolytes through sweating was observed, although the authors believed that under these test conditions these losses were not significant enough to affect hydration or electrolyte levels.

Heckman, Sherry, and Gonzalez (2010) review current data on the marketing of EBs as well as current research on the health benefits and risks associated with their main active ingredients. Globally EBs are experiencing explosive growth and are expected to continue to gain popularity with young adults, particularly in light of an increasingly health-conscious society. They note that while anecdotally there are reported cases of negative health consequences as a whole the concentrations of key ingredients found in most of the major EB brands that dominate the market are in quantities that are not detrimental. In addition to sugar and caffeine, the most common other active ingredients found in energy drinks include B vitamins, ginseng, guarana, taurine, and yerba mate. To this end they call for further research on the potential health risks associated with heavy consumption of these drinks as well as warning labels when elevated levels of their active ingredients are present.

In order to ascertain if consuming EBs is safe in conjunction with exercise, Higgins, Tuttle, and Higgins (2010) conduct a literature review of peer reviewed journals relevant to this topic. The literature review focuses on the potential health effects of the most common EB active ingredients upon non-athletic consumers however makes recommendations for both athletic and non-athletic consumers. None of the ingredients are noted to pose significant risks, either by themselves or in combination with other typical EB components, when in dosages found in most popular, commercially available EBs. Of particular interest they note recent literature which supports the notion that the kidneys demonstrate remarkable efficiency in maintaining adequate hydration even with regular consumers of caffeine (excluding large dose users). Perhaps of greatest interest, while the remaining active ingredients fulfill various nutritional and energy requirements, most are in quantities insufficient to offer therapeutic benefit, with the notable exception of sugar, which according to the authors is of an appropriate dosage for a typical EB (when consumed for exercise purposes). Persons who do not normally consume caffeine or those who have refrained from caffeine consumption in excess of 7 days are more susceptible to the diuretic effects of caffeine. In conclusion the authors note that consumption of a single EB per session is safe but consuming multiple drinks, or in combination with alcoholic beverages or other caffeinated drinks should be avoided. Last, persons with preexisting cardiac conditions should consult their physician prior to consuming EBs.

Duchan, Patel and Feucht (2010) conduct a similar literature review that focuses on the effects of EBs upon performance as well as the nutritional benefits of their most common active ingredients. They note that the amount of sugars present in most common commercially available EBs contain sugars 2 to 3 times the recommended daily intake for beverages, and this high concentration of sugar slows the absorption of water. For this reason they recommend consumption of EBs primarily for exercise recovery rather than prior to exercise. Due to the mechanisms of action of caffeine, the authors recommend avoiding concurrent use of EBs and creatine, a common nutritional supplement for athletes. They further note that due to its high caffeine content guarana may have a mild synergistic effect. The authors conclude that the primary performance enhancing benefits associated with EBs are the result of caffeine, and the risks of serious health effects are rare.

In order to assess the efficacy of enhanced athletic performance, Rahnama, Gaeini, and Kazemi (2010) assess the effects of EBs upon oxygen consumption (VO2 max) and time to exhaustion. Two common commercially available EBs are evaluated (Red Bull and Hype) against a placebo. Participants were asked to consume an EB and then perform a treadmill exercise test utilizing the Bruce protocol, which according to the authors ideally produces exhaustion in 9-15 minutes. Results revealed that both EBs had performance enhancing effects upon maximum oxygen consumption and time to exhaustion, without negatively affecting heart rate or blood lactate levels. The authors attribute these findings to the combination of ingredients contained in both EBs.

Collectively the body of literature reviewed suggests that there are some valid health concerns related to EBs, most notably dehydration and cardiac stress, some of which have been substantiated with research. Firefighters appear to be particularly at risk of experiencing both of these health hazards, which is exacerbated by chronic mild dehydration as well as ingestion of cardiac stimulants. Because of this participants in this study were evaluated as to their caffeine use. Based upon the literature it appears that the health effects of EBs are most significantly moderated by caffeine and sugar and like any substance the effects are dose dependent, with dosages of caffeine in the 200-400 mg range posing minimal threat to those not otherwise susceptible to caffeine. Elevated sugar appears to slow fluid absorption and higher dosages of caffeine will affect even those tolerant to its effects. This relationship formed the basis for this study of the health effects of EBs. Because most of the studies reviewed did not involve consumption of EBs in conjunction with exercise and furthermore, called for future research to evaluate the effects of this combination, this research project specifically aimed to measure if an association exists.

Procedures

Inasmuch as this was a medical experiment that involved the use of human subjects, a research protocol (Appendix A) was developed in accordance with Title 45, Code of Federal Regulations, Part 46, Protection of Human Subjects (2005), issued by the Department of Health and Human Services (DHHS). An ad hoc review board was assembled in March 2011 to ensure that the research protocol was ethically, medically, and legally sound and that the study would reasonably provide meaningful results that did not outweigh the risks to the participants. Review board members consisted of Dr. Stewart Dadmun, a retired cardiologist from UCSD Medical Center, Dr. John Carson, a practicing cardiologist from Scripps Memorial Hospital, San Diego, and Dr. Steve Smith, Dean of Cal Western School of Law, San Diego, California. Finally, the services of Kameryn Denaro from San Diego, California were utilized to assist with review of this document for grammatical errors, APA formatting, and statistical tutoring.

Participants were randomly selected "safety" employees from the North County Fire Protection District, which employs approximately 70 full and part-time fire suppression personnel with a mean age of 36.41 years. A total of 24 participants were selected, of which one was excluded as he was unable to complete the study due to an injury (unrelated to the study). As the study sample size ($N = 23$) represents approximately 33% of the firefighting force, with a mean age of 33.48 years, we believe this is a representative sample of the total affected population. Each participant was asked to review and sign a participation agreement prior to participation in the study (Appendix B). To ensure that all participants were healthy enough to participate in this study, they first underwent an annual physical evaluation, which included a stress electrocardiogram. Only active duty firefighters that had passed this physical exam without limitation were allowed to participate.

A double-blind crossover experimental research method was utilized to test our hypotheses that EB consumption poses significant health risks to firefighters because elevated levels of caffeine and sugar: (a) exacerbate dehydration (H_1), and (b) increase cardiac stress (H_2). This research aimed to either support or reject the null hypothesis, that there is no significant difference in either hydration levels or cardiac workload in firefighters when consuming EBs (H_0). A double-blind crossover design was selected, wherein each participant randomly received either an EB or a placebo beverage (PB), in order to account for both cohort trends as well as individual participant physiologic differences. Ultimately each participant received both, although neither researcher nor participant knew in which order they were given.

In order to rule out a cumulative effect of EBs participants were instructed to refrain from consuming EBs 48 hours prior to testing, and each test was separated by a washout period of at least 48 hours to ensure they had eliminated the active EB ingredients from their body. Because fluid absorption can also be affected by food consumption, participants were tested during the same time of day for each of the two tests. Participants were instructed to practice normal dietary habits in order to simulate "real world" conditions, which invariably would include mild consumption of alcohol and/or caffeinated beverages. Although it is recognized that by not controlling for these non-experimental variables that there is an increased likelihood of a Type 1 error, this was a trade-off we were willing to accept in order to obtain better internal validity.

The study was conducted with two randomly selected groups of firefighters: those who first consumed one 16 ounce Rockstar Punched ® brand EB those who first consumed a PB. It should be noted that this particular EB contained 240 mg of caffeine per 16 oz container. The PB consisted of a 50/50 mixture of club soda and water (16 oz total) and one Crystal Light Fruit Punch ® brand drink mix, which is both sugar and caffeine free. During the entire study period participants were instructed to refrain from consumption of any other beverages.

Upon entry into the study subjects were first questioned regarding their caffeine use and age; those that signified that they consumed 0-1 caffeinated beverages per day were categorized as "non-caffeine users" and those who consumed 2 or more caffeinated beverages per day were categorized as "caffeine users." Participants were instructed to commence the test with an empty bladder, so it was presumed that baseline was an empty bladder. The basis for timing of testing intervals was based upon peak serum levels of caffeine and sugar. Serum caffeine levels peak 1 to 1.5 hours after ingestion, with a half-life of 3 to 6 hours (Hardman J.G., and Limbird L.E, 1996). Similarly, ingestion of sugar results in peak serum glucose levels approximately 1 hour after consumption and is not affected by the type of glucose consumed (Wahlqvist et al., 1998).

Resting ECG and hydration were measured before and after testing both to establish a baseline and to rule out individual differences in participants. The sequence of measurements was for subjects to first weigh themselves, urinate, take vital signs, and finally bioimpedance analysis (BIA). The specific parameters that were measured were urine specific gravity (SPGR), urine output (U/O), resting electrocardiogram (ECG), blood pressure (BP), heart rate (HR), total body water (TBW), intracellular fluid (ICF), extracellular fluid (ECF), and body mass index (BMI). Body weight was utilized as in input for BIA.

After consuming either 16 ounces of the EB or PB participants were instructed to wait 60 minutes (performing only minimal physical exertion, such as reading), at which time they were again evaluated for the same parameters. They were then instructed to participate in a uniform 30 minute treadmill exercise routine, targeted to between 70% and 85% of the maximum heart rate, based upon an age adjusted formula (CDC, 2011). Within three minutes of completion of exercise they were evaluated for the same parameters, with a fourth and final measurement of these parameters occurring one hour after exercise. Upon completion of the test each participant was questioned regarding their subjective physical feelings experienced during the study. A list of these questions is provided in Appendix C.

A second identical evaluation was conducted by switching the study and control groups, with participants consuming the alternative beverage to their first test. A minimum 48-hour washout period was utilized to ensure all remaining EB has been eliminated from the first testing period. Subjects were tested approximately the same timeframe (morning or afternoon) for each phase of the trial (commencing at either 9-10 am or 1-2 pm) so that the impact of daily dietary routine would be consistent among participants.

Body composition and hydration was assessed by using the ImpediMed ® Model SFB7 BIA analyzer (ImpediMed Ltd., Eight Mile Plains, Queensland, Australia) with subjects supine and their arms positioned by their sides, but separated from their body with their palms down and legs slightly apart. All metal was removed from the body prior to measurement. Dual tab electrodes (5 cm spacing) were attached to the foot and hand in accordance with the manufacturer's instructions. Body composition results were compared against the National Health and Nutrition Examination Survey (NHANES-III) data set results (Chumlea et al., 2002), which includes age-adjusted means.

All cardiac output variables were measured with a Lifepak 12® monitor/defibrillator (Physio-Control Inc., Redmond, Washington), including HR, BP, and ECG. All vital signs were taken with participants resting in a seated position. In order to ensure consistency between participants post-exercise vital signs were taken 3 minutes after completion of exercise. ECGs were taken via a 4-lead electrode placement. Urine specific gravity was obtained by utilizing FDA approved for home-use standard urinalysis dip test strips (URI1017), manufactured by CLIAwaived.com (San Diego, California).

As the basis for this study is heat stress and cardiovascular events experienced during wildland firefighting, it was felt that a metric that simulated exertion equivalent to that encountered during wildland firefighting was needed. The National Wildfire Coordinating Group (NWCG) requires those engaged in active wildland firefighting functions to have an *arduous* level of physical ability. To this end the NWCG established the *pack test* to measure this level of physical performance, which consists of a 3 mile hike on level ground carrying a 45 lb. pack within 45 minutes (Whitlock & Sharkey, 2003). As this was not practical for this study a level of exertion equivalent to the "pack test" was selected. Because a treadmill was utilized for this study this level of exertion was correlated to be equivalent to a 3.5 mph walking pace at a 5-10% grade (Sharkey & Davis, 2008, p. 8). To maintain this level of physical ability the authors recommend aerobic exercise 3 times a week, thereby supporting the notion that this level of exertion represents a realistic expectation for wildland firefighters to maintain a reasonable level of fitness and is therefore a valid measurement tool for this study. The Centers for Disease Control (CDC) recommends that target heart rates for aerobic exercise are between 70-85% of maximum heart rate, which is calculated as 220-age (CDC, 2011). In order to ensure safety of the participants, the Borg Rating of Perceived Exertion scale (RPE) was utilized (Borg, 1998). A RPE of 14-17 is consistent with an "arduous" level of exertion and achieves an aerobic level of exercise (Glencoe, 2008). Study participants were allowed to adjust the treadmill grade in order to maintain both their heart rate within the 70-85% range and their RPE between 14 and 17. It was felt that utilization of the RPE and the target maximum heart rate range of 70-85% would offer physiologic parameters that would ameliorate variability associated with allowing participants to adjust the treadmill grade.

Statistical analysis of the data was performed utilizing Minitab® version 16.1.1 statistical analysis software. Three methods of statistical analysis were employed. A level of significance (α) of 0.05 was used for all statistical tests. As we were interested in the difference between paired variables (for example, post-exercise hydration with EBs vs. PBs), we utilized a paired *t* test. Measurement of the difference between paired variables (for example, EB post-exercise hydration vs. PB post-exercise hydration) was selected specifically for this study because the goal of hydration during firefighting is to maintain or ideally improve overall hydration, and we are interested in the relative impact of one versus another. This procedure tests the null hypothesis that the average difference within pairs is equal to a hypothesized value. A *t*-value is considered significant when it exceeds a certain pre-determined value, based upon α and the degrees of freedom (*df*), which is the number of items in a sample minus 1. In a paired *t*-test we also obtain a *p*-value; when the *p*-value is less than α the null hypothesis is rejected.

In order to determine to what extent each of the experimental variables would have upon hydration and cardiac workload, we utilized a multiple linear regression analysis. This procedure produces an equation or model to describe the statistical relationship between the predictors (e.g., age, BMI, caffeine use) and the response variable (e.g., post-exercise hydration). Regression analysis results indicate the statistical significance of the relationship between the predictor and response by providing a coefficient (*B*) for each predictor. Coefficients represent the average change in the response variable for one unit of change in the predictor while holding other predictors in the model constant. An R^2 value is provided which demonstrates the "goodness of fit" of the model against the actual data, which ranges from 0 to 1. The higher the R^2 value the more complete the model is in explaining variance in the response variable. A *p*-value is also provided for each coefficient, which tests the null hypothesis that the coefficient is equal to zero and therefore no effect. A *p*-value less than 0.05 suggests the predictor is meaningful.

Finally, in order to develop a model that would best predict change in various response variables we utilized a stepwise regression analysis. Stepwise regression is a method of model building that both adds and removes predictors as needed for each step. According to the Minitab® statistical glossary, their software stops model building "when all variables not in the model have *p*- values that are greater than the specified alpha-to-enter value, and when all variables in the model have *p*-values that are less than or equal to the specified alpha-to-remove value" (Minitab, 2010). Explanatory variables that remain based upon the α values (0.05) are significant predictors, and will be accompanied by an R^2 value ranging from 0 to 1, which explains the degree to which the explanatory variable accounts for change in the response variable.

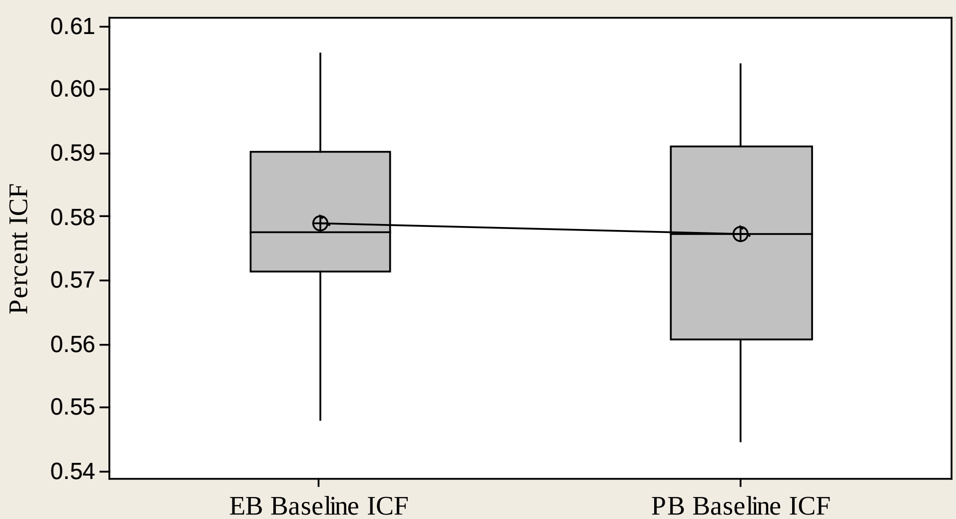
There are a few noteworthy limitations of this study. To begin, as one of the study goals was to replicate "real world" conditions, which would include variability in participant hydration and consumption of other caffeinated drinks, in so doing the participants were not necessarily at the same physiologic baseline. It is for this reason that individual participants were tested during the same time of day for each test. It is likely participants could have added several pints of fluid (either from food or drink) to their total body water (TBW) because the test would have been either after breakfast or after lunch. Percentage of TBW was not utilized for evaluation of hydration in this study since fitness level can also affect TBW percentage. Inasmuch as lean muscle contains 73% water whereas fat contains only 10% water, individuals with greater fat mass will inherently have less TBW relative to their body weight (Rakowski, 2002). Finally, unlike "real world" wildland firefighting conditions the exercise environment in this study was climate controlled, did not involve the wearing of personal protective clothing, and exercise times were restricted to relatively short intervals (30 minutes) to control for environmental influences as well as to avoid the potential of unnecessary risk.

To summarize the methods employed in this study, as firefighters do not normally restrict their diets prior to or during work (with the obvious exception of alcohol on duty), and because they might be called to fight fire at any given moment, we attempted to utilize an evaluation method that would mimic the health effects of EBs upon firefighters during firefighting. As firefighting can rapidly alter hydration as well as cardiac workload BIA was selected to most accurately capture real-time hydration status. As the goal of hydration during firefighting is to maintain or increase hydration levels, evaluation methods were selected that measured the relative differences between the effects of EBs and PBs upon hydration at the cellular level.

Results

Of the various hydration values collected (TBW, ECF, and ICF), ICF is considered to be the most accurate reflection of hydration status (Rakowski, 2002). Therefore ICF was the parameter selected for all hydration evaluation. A paired *t*-test analysis of the mean difference in pre-test (baseline) hydration levels revealed no significant difference between the two tests. Figure 1 presents two box plots of baseline ICF hydration. The first is for the EB test and the second is for the PB test, with the circle representing the average percent ICF for each test. From the figure we see that there was only a 0.17% difference in the average baseline percent ICF when comparing the day the firefighters drank EBs compared to PBs.

Figure 1
Baseline Hydration in EB vs. PB Tests



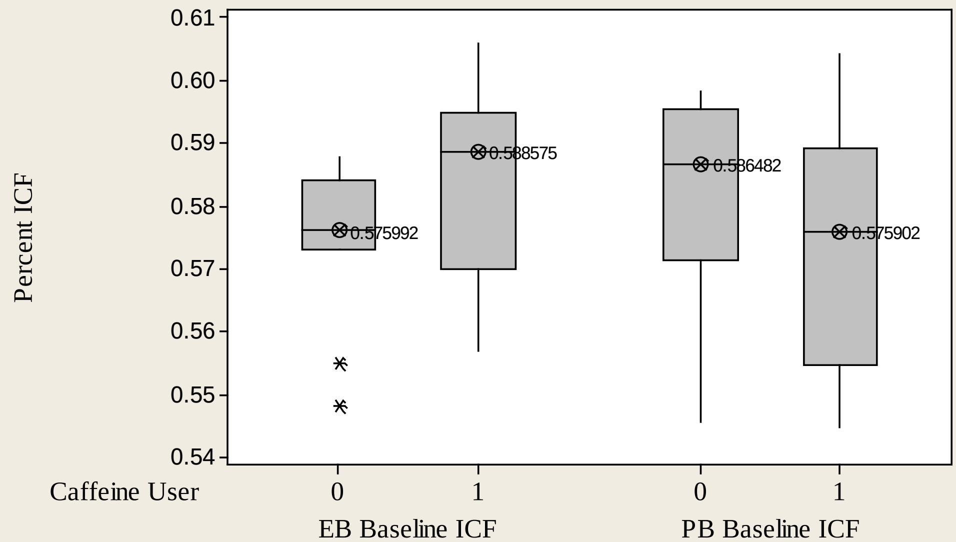
t(44)=.64, p<.531, 95% CI [-0.00390, 0.00735]

In comparing these baseline ICF averages to correlated age-adjusted population means (Chumlea et al., 2002), collectively participants were found to be on an average 1.2% dehydrated (*SD* = 0.18%) relative to the mean general population ICF of 59.0% for the mean participant age (*M* = 33.48, *SD* = 9.48). Additionally, when adjusting for age, 13% of participants exhibited a baseline ICF 2% below average and 21% of participants exhibited a baseline ICF 3% below average for both EB and PB tests. With one exception, these were the same individuals in both tests.

As caffeine use was identified in the literature as being the most significant determinant of hydration (Riesenhuber et al., 2006; Duchan et al., 2010), baseline hydration was also evaluated against the variable *caffeine user*. Based upon participant questioning during entry into the study, 52% of participants were categorized as "caffeine users," of which 17% indicated that they consumed the equivalent of 4 or more cups of coffee per day. Figure 2 presents four box plots representing baseline percent ICF for both caffeine and non-caffeine users (caffeine users identified with a "1"), with the circle representing the average for each test. This figure illustrates that there was approximately a 1% difference in median pre-hydration values for caffeine versus non-caffeine users for both the EB and PB tests. Caffeine users were 1.2% more hydrated than non-caffeine users at the beginning of the EB test and 1% less hydrated than non-caffeine users at the beginning of the PB test. There are two outliers present in the non-caffeine user EB box plot, which presumably would reduce the mean baseline hydration value for non-caffeine users during this test. As their removal did not significantly alter these findings and because they are within the range of data present in two of the remaining three box plots, they were retained for all data analyses.

Figure 2

Baseline Hydration Comparison Caffeine vs. Non-caffeine Users



In order to determine what factors could influence hydration and cardiac workload, a series of multiple linear regression analyses were performed. Of these analyses only an analysis of pre and post-exercise ICF after EB consumption as the response variables yielded reliable models, with age, baseline ICF, caffeine use, BMI, systolic, and diastolic BP as the predictor variables. Between these two models post-exercise results were selected because they represent the most critical time period (after exercise), during which firefighters could be potentially most susceptible to the effects of dehydration. Table 2 represents an analysis of variables predicting post-exercise hydration following EB consumption, based upon the following regression equation: EB post-exercise ICF% = 0.051 - 0.000381 BMI - 0.000122 age + 0.887 EB baseline ICF% - 0.00008 caffeine user + 0.000204 EB baseline systolic + 0.000001 EB baseline diastolic.

Table 2
Summary of Regression Analysis for Variables Predicting Post-exercise Hydration Following EB Consumption:

Variable	*B*	*p*-value
Constant	0.0508	0.656
BMI	-0.0003813	0.498
Age	-0.0001216	0.630
EB Test Baseline ICF%	0.8865	0.000
Caffeine User	-0.000082	0.984
EB Test Baseline Systolic	0.0002035	0.381
EB Test Baseline Diastolic	0.0000012	0.997

Note: R^2 = 79.7%, R^2 (adj.) = 72.1%,

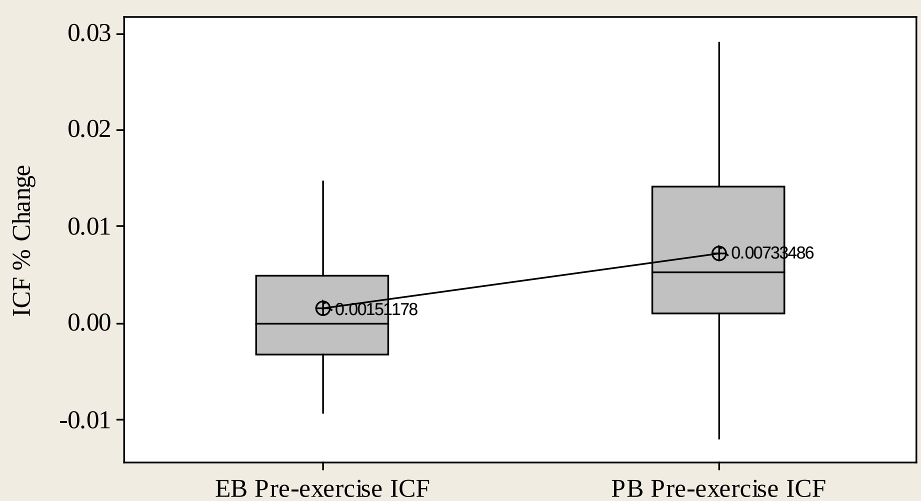
Results revealed that collectively these variables represent a model that accounts for nearly 80% of the variation in post-exercise ICF, with a relatively high R^2 value of 79.7%. Of the predictors however only baseline ICF was found to be statistically significant ($B = 0.8865$, $p = .000$). This indicates that for each 1% increase in baseline ICF there is a corresponding 0.88% increase in post-exercise ICF. None of the remaining variables were found to significantly influence post-exercise ICF.

A stepwise regression analysis was then performed to determine the model with the best predictive power of post-exercise ICF, utilizing the same six predictor variables as noted in the multiple linear regression analysis. The only explanatory variable that was kept based in the stepwise procedure was baseline hydration ($\alpha = .05$, $N = 23$). With baseline hydration as the explanatory variable and post-exercise ICF as the response variable we had an $R^2 = 75.6$. Therefore, 75.6% of the variation in post-exercise ICF can be explained by baseline hydration.

Because caffeine use was not demonstrated to be a significant determinant of pre or post-exercise ICF, the remainder of analyses did not take this variable into consideration. The purpose of this study was to evaluate the relative change in hydration and cardiac workload. Therefore paired *t*-tests were used to analyze the differences in hydration between the EB and PB tests. In order to adjust for participants' baseline hydration we considered the difference between pre-exercise hydration and baseline hydration, post-exercise hydration and baseline hydration, and 1 hour post-exercise hydration and baseline hydration. For example, the evaluation of changes in pre-exercise ICF is determined by subtracting the baseline percent ICF from the pre-exercise percent ICF for each test (EB and PB). We compared these differences via a paired *t*-test. A 95% confidence level was utilized for all such tests.

With regard to hydration, two significant differences were found. First, a 0.58% difference in pre-exercise adjusted for baseline ICF was found. Figure 3 shows two box plots of pre-exercise ICF, with the first representing the EB test and the second representing the PB test. The circle represents the average percent change in pre-exercise ICF relative to baseline. From this figure we see that the EB group realized virtually no increase (0.15%) in pre-exercise hydration whereas the PB group realized a 0.73% increase in hydration.

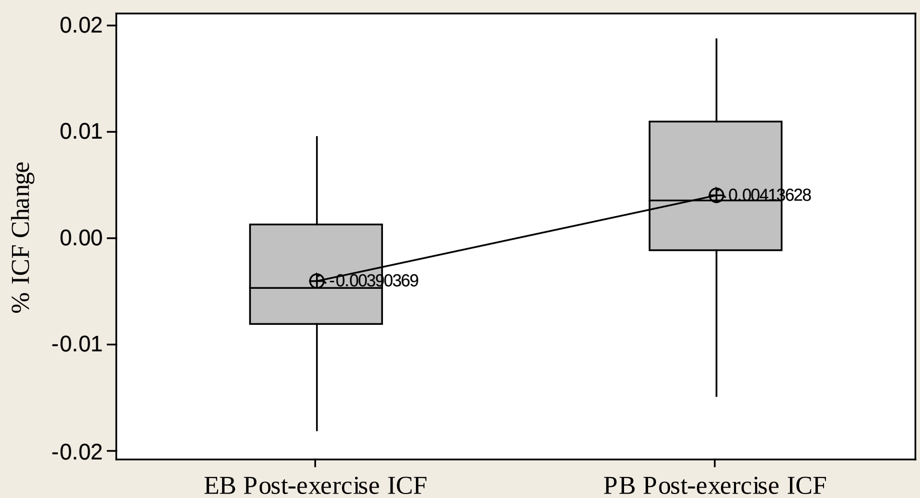
Figure 3
Differences in Pre-exercise ICF



t(22) = 2.27, p = .017

Similarly, a 0.8% difference in post-exercise adjusted for baseline hydration was found. Figure 4 shows two box plots of post-exercise ICF, with the first representing the EB test and the second representing the PB test. The circle represents the average percent change in post-exercise ICF relative to baseline. From this figure we see that the EB group realized a 0.39% reduction in ICF and the PB test realized a 0.41% increase in ICF (Figure 4). In evaluating individual changes in post-exercise ICF when compared to baseline, 11 out of 23 participants (47.8%) experienced a 1% or greater reduction in their post-exercise ICF when consuming an EB. It is noteworthy to add that of the 34% of participants that were noted to be 2% or more dehydrated at baseline, all but one experienced this 1% or greater reduction in post-exercise ICF.

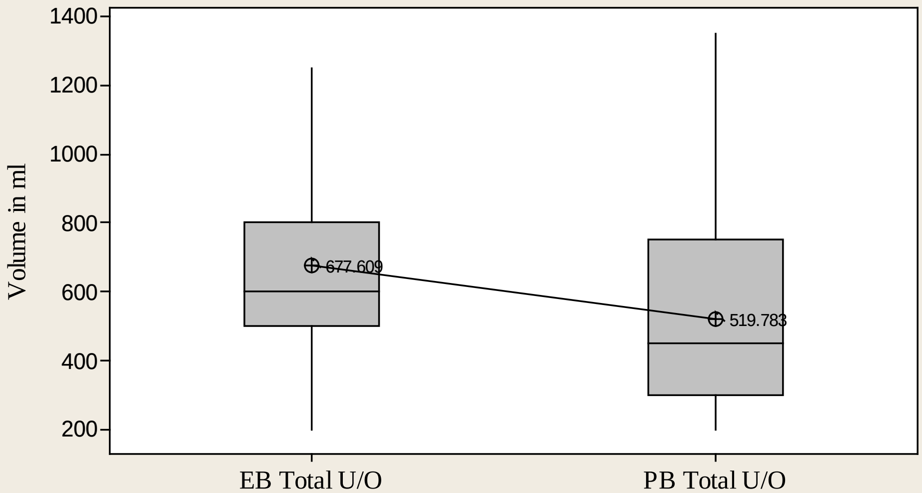
Figure 4
Differences in Post-exercise ICF



t = -3.87, p = 0.000

Cumulative total average U/O (measured prior to exercise, after exercise, and one hour after exercise) was found to be greater for the EB test versus the PB test. Figure 5 presents two box plots representing total urinary output, with the first for the EB test and the second for the PB test. The circle represents the average total urinary output for each group. From this figure we see that the EB group experienced a mean increase of 158 ml relative to the PB group. Differences in SPGR or correlation to ICF were found to be unreliable.

Figure 5
Total Urinary Output

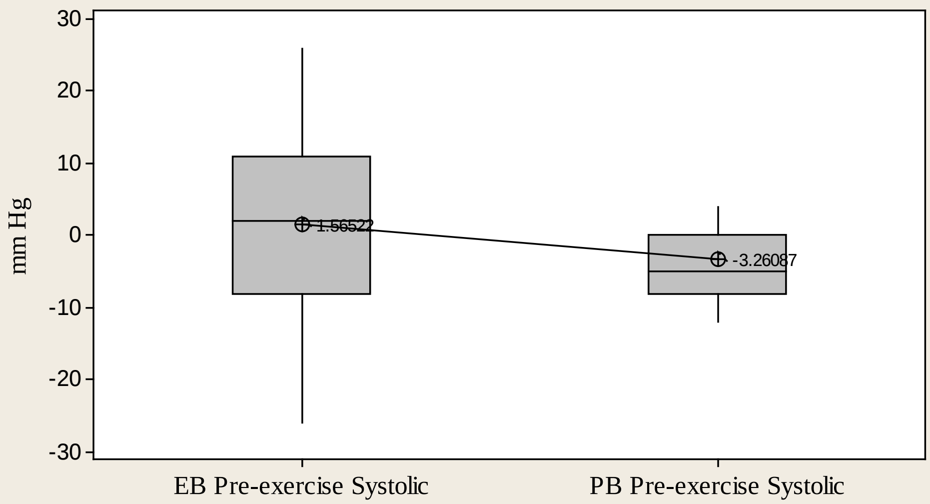


t = 2.91, p = 0.004

Our first hypothesis was that the elevated levels of caffeine and sugar found in EBs exacerbate dehydration. In our sample we saw only a minimal increase in pre-exercise hydration (0.15% vs. 0.73%) when comparing EB versus PB consumption (Figure 3). Similarly, we saw an average difference of 0.8% in ICF when comparing EB versus PB for post-exercise ICF hydration (Figure 4). Since our *p*-values were small (<.05), we reject the null hypothesis . We conclude that true average post-exercise hydration adjusted for baseline is less when people drink EBs versus PBs. Similarly, we conclude that average pre-exercise hydration adjusted for baseline is less when people drink EBs versus PBs.

There were a number of significant changes in cardiac workload as well, however there were no cardiac arrhythmias noted. Figure 6 presents two box plots of pre-exercise systolic blood pressure. The first is for the EB test and the second is for the PB test. The circle represents the average systolic blood pressure. From the figure we see that there was a 4.83 millimeters of mercury (mmHg) difference in the average pre-exercise systolic BP when comparing the day the firefighters drank EBs compared to PBs. We note that the EB group realized an increase of 1.57 mmHg and the PB group realized a 3.26 mmHg decrease.

Figure 6
Differences in Pre-exercise Systolic BP

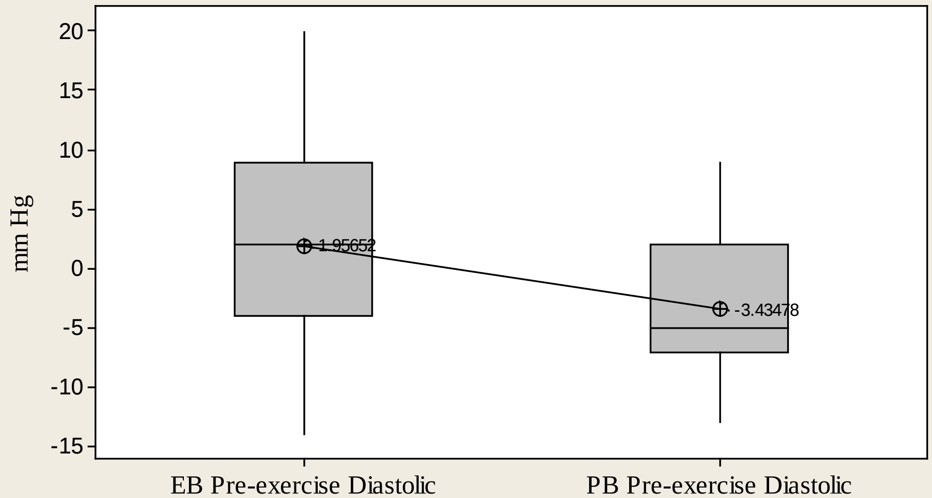


t = 1.78, p = 0.045

Figure 7 presents two box plots of pre-exercise diastolic blood pressure. The first is for the EB test and the second is for the PB test. The circle represents the average diastolic blood pressure for each day. From the figure we see that there was a 5.39 difference in the average pre-exercise diastolic BP when comparing the day the firefighters drank EBs compared to PBs.

Figure 7

Differences in Pre-exercise Diastolic BP

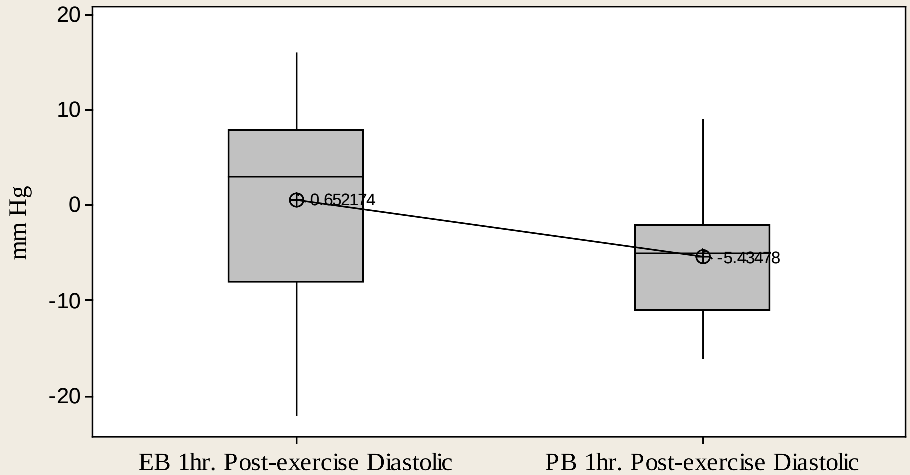


t = 2.35, p = 0.014

Figure 8 presents two box plots of one hour post-exercise diastolic blood pressure. The first is for the EB test and the second is for the PB test. The circle represents the average diastolic blood pressure for each day. From the figure we see that there was a 6.09 mmHg difference in the average one hour post-exercise diastolic BP when comparing the day the firefighters drank EBs compared to PBs. One participant was hypertensive (systolic BP >140 or diastolic BP >90) pre-exercise in the PB study whereas 4 (17%) were hypertensive in the EB study. Similarly, 2 participants (9%) were hypertensive in the PB study post-exercise whereas 4 (17%) were hypertensive in the EB study.

Figure 8

Differences in 1 hr. Post-exercise Diastolic BP

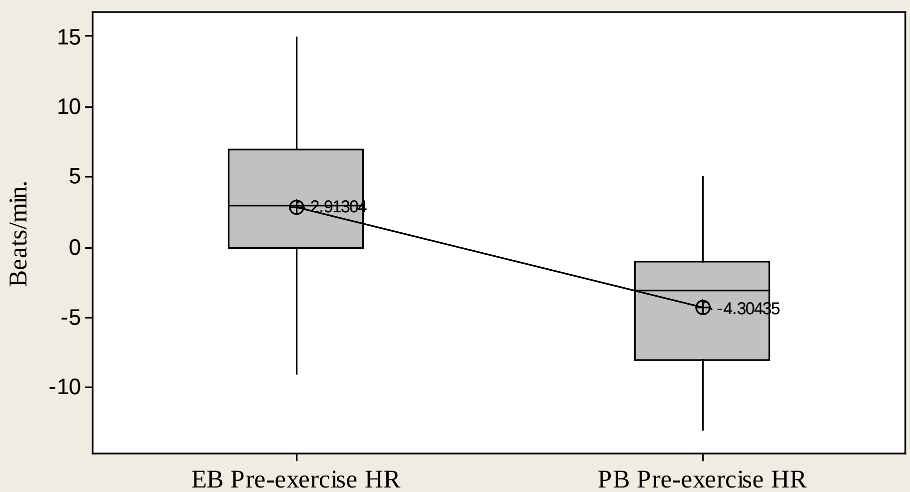


t = 3.57, p = 0.001

There was a consistent difference in HR during all phases of the EB test compared to the PB test. Figure 9 presents two box plots of HRs. Both box plots show the pre-exercise HR; the first is for the EB test and the second is the PB test. The average difference in pre-exercise HR for the day where firefighters drank EBs compared to PBs is 7.22 beats per minute (BPM).

Figure 9

Differences in Pre-exercise Heart Rate

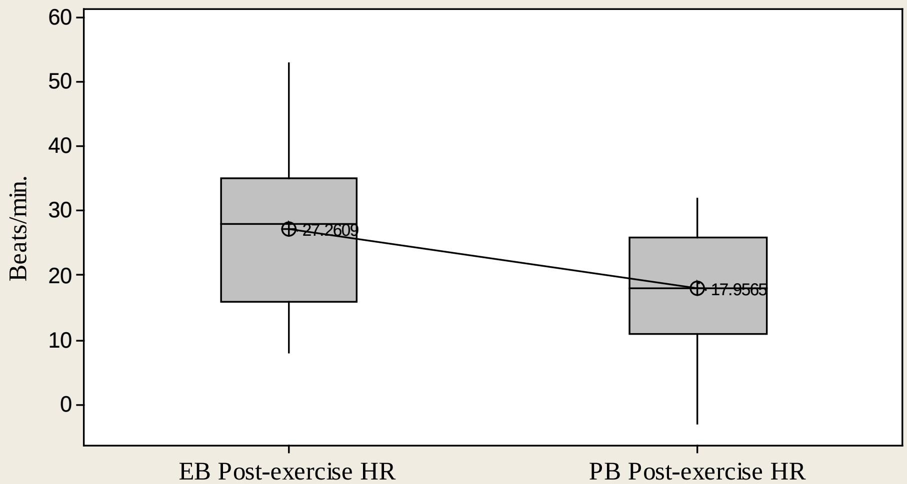


t = 3.89, p = 0.00

Figure 10 presents two box plots of HRs. Both box plots show the post-exercise HR; the first is for the EB test and the second is the PB test. The circle represents the average post-exercise HR. The average difference in post-exercise HR for the day where firefighters drank EBs compared to PBs is 9.36 BPM.

Figure 10

Differences in Post-exercise Heart Rate

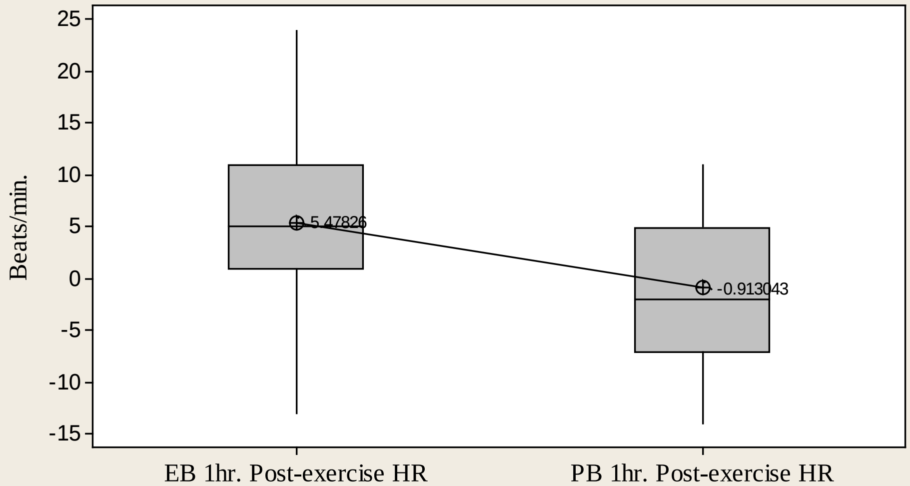


t = 4.19, p = 0.00

Figure 11 presents two box plots of HRs. Both box plots show the one hour post-exercise HR; the first is for the EB test and the second is the PB test. The average difference in one hour post-exercise HR for the day where firefighters drank EBs compared to PBs is 6.39 BPM. One hour post-exercise HR for the EB group was elevated an average of 5.48 BPM (*SD* = 8.56) from baseline.

Figure 11

Differences in 1 hr. Post-exercise Heart Rate



$t = 3.33$, $p = 0.002$

The second hypothesis was that elevated levels of caffeine and sugar found in EBs are associated with an increase cardiac workload. In our sample we saw multiple findings that demonstrated significant differences in pre and post-exercise HR as well as pre and post diastolic BP. Since our *p*-values are small, we reject the null hypothesis and conclude that cardiac workload is significantly increased when consuming EBs compared to PBs both prior to and after exercise.

Discussion

Although there was a significant difference between pre-hydration levels between caffeine and non-caffeine users in the EB test, which could arguably affect post-exercise ICF, given the nature of the differences between these two groups it is believed that more equivalent baseline ICF values would have likely only increased differences in post-exercise ICF between the EB and PB. As noted in the results, a regression analysis of the variables measured in the study anticipated to influence ICF (age, baseline ICF, caffeine use, BMI, systolic BP, and diastolic BP) revealed that baseline ICF was the only significant determinant of post-exercise

ICF when consuming EBs, meaning that overall caffeine use was not demonstrated to predict intracellular hydration once baseline hydration is taken into account. While this finding might appear to refute prior research which stipulates that regular caffeine users are less susceptible to the dehydration effects associated with caffeine (Higgins et al., 2010), it is probable that the high sugar content of the test EB influenced absorption (Casa et al., 2000; Duchan et al., 2010).

Although total U/O was 157.8 ml greater in the EB test and statistically significant (t = 2.91, p = .004), the net positive increase in ICF (1 hour post-exercise ICF – baseline ICF) was only 0.41% in the PB test and not statistically significant (t = 1.40, p = .087). What this means is that by the end of the evaluation period (1 hour post-exercise) the significant dehydrating effects of EBs experienced both pre-exercise and immediately post-exercise were no longer statistically significant as a whole. As this 0.41% relative increase in hydration represents 5.3 oz, and a 0.41% hydration change represents a 6.6 oz increase in TBW (M= 103.98, SD = 11.93), 80% of the difference in 1 hour post exercise ICF can be attributed to increased urinary output associated with EBs, presumably caused by the caffeine and consistent with the literature (Higgins et al., 2010). The fact that this difference was nearly double (0.8%) immediately post exercise also supports prior research by Casa et al. (2000) and Duchan et al. (2010), that other ingredients, presumably sugar, are responsible for delayed fluid absorption. Therefore the physiologic impact of EBs upon hydration could be explained primarily by the mild but relatively immediate diuretic effect of caffeine followed by the sustained delayed fluid absorption associated with high sugar containing beverages.

Although the study did reveal statistically significant changes in hydration levels between the study and control groups, collectively those levels (0.39% reduction in ICF post-exercise when consuming EBs) fall within what would be considered mild, nonclinical hypohydration (low hydration) rather than potentially dangerous and physically noticeable levels. Notwithstanding, nearly half (47.8%) of the participants experienced a 1% or greater reduction in post-exercise ICF when consuming an EB. Moreover, when considering that participants were on an average 1.2% dehydrated at baseline however, an additional average 0.39% decrease in ICF causes average ICF levels to drop to 1.6%, which approaches a level of dehydration (2%) that begins to affect cognition and physical performance (Kleiner, 1999; Casa et al., 2000). On an average then participants were found to be 1.6% dehydrated after consuming a single EB when compared to baseline, which would be of concern if confronting an extended wildland firefighting assignment. Even more alarming, 13% of participants were 2% or more dehydrated at baseline and 21% of participants were 3% or more dehydrated at baseline. Only 17% presented with adequate baseline hydration levels on both test days. Immediately post-exercise the number of participants that were 3% or more dehydrated following EB consumption more than doubled to 44%, versus 26% when consuming the placebo.

The significance of this finding is that a full one-third (34%) were at a sufficiently reduced hydration level that mental and physical performance would be impaired, and for those 3% or more dehydrated at least 24 hours of rehydration and recovery would be necessary to restore proper hydration levels (Sagawa et al., 1992). During wildland firefighting there is quite often insufficient time to rest, rehydrate, and recover to this extent. Furthermore, of this 34% all but one experienced a 1% or greater reduction in post-exercise hydration when consuming an EB, meaning that those that were already dehydrated were more prone to becoming even more dehydrated when consuming EBs, which is consistent with the findings illustrated in Table 2. Similarly, the 0.8% difference in post-exercise ICF between the EB and PB groups suggests that as a whole those consuming EBs are more dehydrated after exertion while those consuming PBs (a drink equivalent to water) are more hydrated. As this presented an obvious concern, immediately after completion of participant evaluation each participant that was found to be 2% or more dehydrated at baseline received counseling on factors influencing their hydration status.

Individuals that experienced minimal net difference in ICF between the two tests may not necessarily be susceptible to the health effects of EBs. This is of course predicated upon the consumption of a single energy drink, so if consumed in accordance with most nutritionists' recommendations (a single can per 6 hour timeframe), health risks are negligible for persons not otherwise susceptible to caffeine. Consistent with other findings however (Ganio et al., 2007; BfR, 2008; Higgins et al., 2010), consumption of multiple EBs or consumption in conjunction with other caffeine containing substances would increase the risk of significant negative outcomes when consumed in excess of 8.2 mg/kg. Utilizing an average participant weight of 86.4 kg, consumption of 3 EBs (or one to two 8 oz cups of coffee and 2 EBs) would exceed this 8.2 mg/kg threshold. Considering that 17% of participants consumed 4 or more cups of coffee per day, it is likely that consuming a single EB within the same 24 hour timeframe that coffee was consumed would push these individuals over that threshold. As this could present an immediate health concern individuals known to be heavy caffeine consumers were advised of their relative risk of exceeding this threshold. Health risks from prolonged caffeine consumption during firefighting activities (in excess of 300-400 mg per day) could likely result primarily from the cumulative diuretic effect of caffeine (Ganio et al., 2007; Higgins et al., 2010), and potentially as well from increased electrolyte loss from sweating (Del Coso et al., 2009). While the latter conclusion is perhaps speculative, the study by Del Coso et al. (2009) was limited in that participants exercised for 120 minutes in dry conditions, and wildland firefighting assignments routinely exceed 12-24 hours.

The relative changes in cardiac workload, while significant, may not necessarily pose a substantial risk, although like hydration, do reveal that EBs do serve to influence it. For example, pre-exercise HR only increased 2.9 BPM relative to baseline in the EB test, which would not be statistically significant. Similarly, systolic and diastolic BP only increased 1.6 and 2.0 mmHg from baseline respectively. Thus it is from the relative change in EB versus PB tests that we derive a significant change. Notwithstanding, considering that participants were on average 1.2% dehydrated relative to the norm, consumption of 16 oz of fluid followed by one hour of rest should stimulate a mild parasympathetic response, thereby lowering HR and BP, particularly if participants were mildly dehydrated. While this occurred in the PB group, taken as a whole the inverse occurred in the EB group, indicating that in general EBs will increase cardiac workload, which is undesirable in a work environment where excessive cardiac stress is associated with a significantly increased incidence of cardiovascular events (USFA, 2002). Perhaps most significant was the difference in HR both post-exercise (9.3 BPM) as well as one hour post-exercise (5.48 BPM) in the EB test when compared to the PB test. Finally, both pre and post-exercise the number of hypertensive participants at least doubled in the EB tests versus the PB tests, although this affected only 17% of the study group. As this too presents an immediate health concern those individuals found to be hypertensive were counseled regarding their cardiac response to EB consumption.

Because EBs would be considered “high energy” beverages, consistent with the *Adventist Health Study* then regular consumption is likely to yield long-term cardiovascular health consequences. In light of findings from the American Heart Association (AHA) study (Lopez-Garcia et al., 2006) this conclusion is made based upon the differences between regular coffee and energy drinks, which contain much higher levels of sugar (compare labels) and, because of their fluid volume are likely to be used as fluid replacement. Unlike the *Adventist Health Study*, the AHA study did not evaluate hydration per se, which may partially explain differences in their findings. Simply put, by regularly consuming EBs firefighters are placing themselves in the "high energy drink" consumption category as identified in the *Adventist Health Study*. Since prior research has revealed that caffeine is a diuretic and sugar inhibits absorption of water (Casa et al., 2000; Duchan et al., 2010), it is presumably the combination of ingredients in energy drinks that poses health risks. So while consumption of a single EB (in the absence of other "high energy" beverages) is less likely to produce a short-term health risk to most firefighters, it is possible that they may be associated with an increase in long-term cardiac health risks based on outside research results.

The rationale behind this disparity in the effects of coffee versus EBs may lie in the mechanism of action of caffeine. Inasmuch as caffeine inhibits insulin secretion thereby reducing glucose tolerance (Thong and Graham, 2002), it is plausible that the significant difference in sugar content of coffee versus EBs may prolong elevated serum blood glucose concentrations which would reflexively prolong insulin secretion. This would be consistent with the findings from Wolever and Miller (1995). More importantly, elevated serum glucose levels in non-diabetic persons have been associated with nearly a fourfold increased risk of death (Capes et al., 2000). It appears that this is attributable to increased levels of cytokine, which has been implicated to increase insulin resistance (a precursor to diabetes) and vascular plaque destabilization, which increases the risk of heart attack and stroke (Esposito et al., 2002).

Considering that physical and cognitive performance begins to deteriorate with total body water loss of 2% or greater (Kleiner, 1999; Casa et al., 2000), and 58% of firefighters performing 30 minutes of physical exertion were found to have lost in excess of 2% of total body weight in sweat (Boyle, 2008), consumption of any beverage that affects even short-term hydration would seem counterintuitive, particularly in light of this study's findings. This is particularly salient given the nature of firefighting, which frequently involves transitioning from a cool to a hot environment without adequate time for acclimatization, because under such conditions the body exhibits increased demands for fluids and electrolytes, and can take from 5-10 days to acclimatize (Casa et al., 2000).

Although the majority of the findings presented herein suggest limitation of caffeine and sugar consumption, there are some psychoactive benefits associated with caffeine. 17% of study participants reported only positive subjective feelings associated with the EB (increased alertness and/or increased energy). Job assignments of long duration result in fatigue, which is not at all uncommon during wildland firefighting assignments. Such assignments often require driving for several hours through the night and immediately receiving a firefighting assignment upon arrival at an incident. Studies on sleep deprivation illustrate that after 16 hours without sleep, cognitive abilities begin to suffer (Van Dongen, Maislin, Mullington, & Dinges, 2003), and driver fatigue is responsible for 10-15% of vehicular accidents (Radun & Summala, 2004). Because the nature of firefighting can include long duration assignments accompanied by mental and physical fatigue, the risk associated with impaired reflexes and cognition must be weighed against the risk associated with cardiac stimulation and dehydration.

Many of the findings presented in this study either provide clarification to prior EB literature or support it. Inasmuch as many of the previously held perceptions of the health effects of EBs were based upon research pertaining to coffee, this study should serve to establish a more definitive distinction. Most definitively we have established an inverse relationship between EBs and exercise hydration relative to water, and a direct correlation between EBs and increased cardiac workload. At the very least the simple performance of this study has substantially raised NCFPD employee awareness of the importance of maintaining proper hydration as well their individual physiologic responses to EBs. Optimally it will provide guidance for regulation of EB consumption in the firefighting environment.

Recommendations

The purpose of this study was to determine if the use of EBs creates a potentially dangerous level of dehydration or cardiac workload to firefighters, given the continued prolific use in spite of suspected health risks. Findings revealed provide the basis for a number of firefighter health and safety recommendations pertaining to EBs for NCFPD as they pertain to firefighting activities, fitness for duty, pre-employment physical examinations, rehabilitation, routine physical fitness, and maintenance of overall cardiovascular health. Based upon the specific recommendation implementation may require policy change, inclusion into training materials, sharing in appropriate firefighter health and safety venues, publication in fire service related journals, individual counseling, or a combination thereof.

With regard to firefighting recommendations it should first be noted that in this study had participants been required to exercise for longer periods of time, wearing full wildland personal protective equipment in hot, dry conditions without a recovery period it is likely that their cellular hydration would not have an opportunity to recover. Considering the short-term diuretic effects associated with caffeine, the delay in fluid absorption associated with glucose-laden beverages, and the delay in acclimating to physical exertion in hot environments, the doubling of the number of participants whose dehydration exceeded 3% following EB consumption, the risks associated with continued exertion in hot environments, and the time necessary to sufficiently restore proper hydration, line supervisors, Safety Officers, and Medical Unit personnel would be justified in restricting or eliminating EBs in the wildland fire environment. In fact, some Cal Fire Type 1 IMTs have already initiated this policy (R. Voght, personal communication, May 11, 2011). Quite simply, as physiologic response to EBs under these conditions has not been tested and an inverse relationship between EBs and hydration has been established in this study, it would be remiss for persons responsible for the health and safety of line personnel to knowingly allow their consumption in the wildfire environment, or for that matter any in firefighting environment with prolonged physical exertion. Inasmuch as the author of this study is directly engaged in the IMT community this recommendation will be shared via relevant IMT networks.

As physical and cognitive performance can be impaired beginning at dehydration levels exceeding 2% (Kleiner, 1999), and recovery for dehydration in excess of 3% is likely to take at least 24 hours (Sagawa et al., 1992), there is a nexus between hydration levels and fitness for duty. As it is virtually impossible to quantitatively measure this on a routine basis, supervisors are justified in providing direction that maintains adequate hydration. At the very least, limitation of caffeine consumption to less than the documented daily maximum threshold of 8.2 mg/kg would be justifiable, based upon the findings of Ganio et al. (2007). Using the average pre-test weight of participants in this study, an 86 kg male would reach this threshold at approximately 700mg or one to two 8 oz cups of coffee and 2 EBs, or an equivalent combination. This recommendation will be forwarded to NCFPD’s Health and Safety Committee for further investigation and implementation (Appendix D). Because 21% of all participants exhibited dehydration in excess of 3% prior to test commencement, and because nearly half (47.8%) experienced a reduction in post-exercise ICF in excess of 1%, each participant received a written summary of their individual EB study results and recommendations

(Appendix E), in addition to immediate verbal counseling upon study completion when significant findings were noted (for example, hypertension).

Inasmuch as caffeine has been utilized to screen for predisposition to malignant hyperthermia (MH), and has properties similar to other medications known to induce MH (Hopkins, 2000), future research should explore the effects of EBs upon core body temperature. Utilization of Boyle's 2008 research design would provide useful comparative data. When considering the possibility that individuals may be predisposed to MH it is conceivable that future firefighter pre-employment physical examinations include pre-screening for MH which, if found to exist, might include pre-employment agreements that restrict consumption of caffeinated beverages while on duty. This recommendation will be forwarded to NCFPD's Health and Safety Committee (Appendix D) and to the NFPA 1582 Committee (Appendix F) for further investigation into the feasibility of conducting pre-employment screening for MH.

These findings alone should emphasize the importance of allowing for proper rehydration and rehabilitation and the impact that this alone can have upon short-term hydration status (Boyle, 2008), as well as long-term cardiovascular health (Chan et al., 2002). Considering that the average level of dehydration present among firefighters in this study (1.2%), and that participants' overall hydration status with PBs was improved even after exercise, NCFPD personnel need to increase their level of hydration at the beginning of the work day. Because firefighting activities involve prolonged physical exertion coupled with high heat, following the guidelines set forth for endurance athletes (Ryan, 2007) would be prudent. During periods of routine daily activity, consuming 11 to 16 eight ounce glasses of water (2600 to 3800 ml) per day is sufficient, with one glass (250 ml) consumed each hour. Prior to exertion or assignment to a fire that amount should be doubled, and 200-300 ml of water should be consumed during every

10-20 minutes of exercise (Casa et al., 2000), and sports drinks will aid in carbohydrate and electrolyte replacement (Ryan, 2007). This particular recommendation will be forwarded to NCFPD's Health and Safety Committee for incorporation into our physical fitness and rehabilitation policies (Appendix D).

From a health and fitness maintenance perspective, based upon study findings and consistent with recommendations in the literature cited herein firefighters should limit themselves to 200-400 mg of caffeine per day while at work (Robertson et al., 1981; Ganio et al., 2007; BfR, 2008; Higgins et al., 2010). From a practical perspective this would include a maximum of two EBs or one EB and one to two 8 ounce cups of coffee in a 24-hour period for a well hydrated individual who is a regular caffeine consumer and is acclimatized to the work environment. Should firefighters still desire the performance and cognition enhancing effects associated with small doses of caffeine (less than 400 mg per day), utilization of a low carbohydrate EB may minimize the dehydrating effects associated with high caloric EBs. As noted in the literature however, the added ingredients in EBs are of insufficient quantities to offer any substantive nutritional benefit (Clauson et al., 2008; Higgins et al., 2010), so EB consumers will need to understand the chief benefit of EBs is their short-term performance enhancement (Rahnama et al., 2010) and cognition enhancing effects (Smit et al., 2004; Scholey & Kennedy, 2004).

Not only would this practice possibly reduce the short-term risks of dehydration, but it could also reduce the long-term cardiovascular health risks associated with elevated sugar consumption, as noted in the *Adventist Health Study* and others. Because firefighters are at an enhanced risk of cardiovascular events and because 44% of firefighter fatalities are the result of cardiac events—46% of which occur during firefighting activities (USFA, 2002)—consuming a substance that elevates heart rate, myocardial irritability, and blood pressure seems counterintuitive given the intense and immediate cardiovascular strain experienced during firefighting. Furthermore, research evaluating the causative factors behind stroke and heart attacks reveal a high degree of association between dehydration and these events (Chan et al., 2002; Rodriguez et al., 2008). The risk of having a heart attack during the early morning hours (6 am to 12 noon) is nearly double that later in the day, and increases in blood pressure and clotting factors—both of which are directly affected by hydration—are believed to contribute to this increased risk (Willich et al, 1989). It is for this reason that Chan et al. (2002) recommend hydration primarily via water and avoidance of diuretic and high energy beverages, and Kurabayashi et al. (1991) recommend hydration with 8 to 16 ounces of water prior to sleep specifically to reduce the risk of stroke. Inasmuch as these recommendations are advisory more so than regulatory they will be forwarded to NCFPD's wellness program coordinator (Santa Ana College) for incorporation into their training curriculum.

As this study was not intended to measure true wildland firefighting conditions replication of this research under those conditions might yield more discriminating results. Given the extreme conditions present during wildland firefighting, future research that more closely resembles the environmental, climatic, and physical exertion conditions present during such firefighting activities would serve to validate the extent to which EBs would produce untoward effects. The fact that this study specifically evaluated baseline intracellular hydration and that this was the only experimental variable to affect post-exercise hydration, it is possible that prior inconclusive research on the diuretic effects of caffeine may not have taken this factor into consideration. To this end future similar research should consider BIA assessment of baseline hydration status to control for this variable. Finally, although not a focus of this study the literature review brought to light the effect caffeine has upon suppressing insulin production. It is plausible that prolonged elevated serum glucose levels would result from sustained caffeine consumption, potentially prolonging hyperglycemia. Considering the study that correlates elevated glucose levels to increased mortality (Esposito et al., 2002, Capes et al., 2000) future research should evaluate the specific effects of energy drinks upon serum glucose levels over a period of time and evaluate these findings against those with impaired glucose tolerance (diabetics or pre-diabetics).

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Appendix A

Energy Beverage Research Protocol

Problem Statement: Energy beverages (EBs) have grown in popularity, including among members of the fire service. Due to their high caffeine and sugar contents however, it is believed that EBs contribute to dehydration and increase the incidence of cardiac arrhythmias. In addition to caffeine, EBs can contain such ingredients as guarana, taurine and yerba mate, which also act as stimulants. There is currently scant literature on the subject. Notwithstanding, some are beginning to make policy decisions based upon such beliefs. To begin, several European countries have banned EBs (Reissig, Strain and Griffiths, 2009). During the 2009 Station Fire EBs were banned from the incident. Some EBs contain warnings limiting consumption quantity and in some cases recommend refraining from consumption for individuals with hypertension or heart disease. Locally, our contract wellness institution specifically request that participants refrain from consuming EBs prior to fitness evaluation. Many firefighters continue to use EBs at or before work, but the use of such drinks may contribute to dehydration and cardiac arrhythmias, creating a potential health risk to personnel.

Justification and Use of Results: Knowledge obtained from this research will provide the fire service with the necessary information to make policy decisions on the consumption of EBs. This research will identify if EBs can be consumed on duty and if there are any restrictions as to the degree of consumption. Ultimately, the goal is to maintain firefighter safety by preventing heat related illness, for which dehydration is a significant contributing factor. Results will be disseminated via the National Fire Academy’s Learning Resource Center Library, North County Fire Protection District’s Health and Safety Committee, and individual study participants.

Results will also be shared with Impedimed Ltd., which has provided the BIA testing device. Additionally, results may be published in relevant fire service related trade journals.

Theoretical Framework: Previous research on firefighter hydration has revealed that an overwhelming proportion was mildly dehydrated, with a significant proportion (22%) moderately dehydrated. This presents a significant health risk to those involved in strenuous activities such as firefighting, particularly where rehydration can be a challenge (Boyle, 2008, p. 58). Current research on this topic primarily consists of the effects of caffeine and coffee and the findings are inconsistent. There appears to be minimal scholarly literature relevant to the effects of EBs upon hydration and cardiac effects, and what literature does exist appears to be contradictory (Boyle, 2008, Heckman, Sherry, and Gonzalez de Mejia, 2010). It is therefore hypothesized that that EB consumption poses significant health risks to firefighters because elevated levels of caffeine and sugar: (a) exacerbate dehydration (H_1), and (b) increase cardiac stress (H_2). This research aims to either support or reject the null hypothesis, that there is no significant difference in either hydration levels or cardiac workload in firefighters when consuming EBs (H_0).

While there are many active ingredients in EBs, based upon the literature review it appears that caffeine and sugar have the greatest moderating renal and cardiac effects and therefore, the study will be structured around measuring the effects of these primary substances. As both are readily absorbed (peak plasma levels within 1 hour of consumption) subjects will be evaluated 1 hour after consumption (Robertson, Wade, Workman, Woosley, & Oates, 1981). Additionally, although the sugars delivered in EBs may come in various forms, prior research upon the glycemic effects of various sugars reveals little difference in rate of absorption (Wahlqvist, Wilmshurst, & Richardson, 1978; Wolever & Miller, 1995).

General Objective: The purpose of this research is to determine if the use of EBs creates a potentially dangerous level of dehydration to firefighters (>2% total body weight), or increases the incidence of cardiac arrhythmias.

Specific Objectives: The objectives of this research are to identify the degree of EB consumption by firefighters, the resultant effect upon their levels of hydration and electrocardiogram, and how severe the resultant dehydration and cardiac arrhythmias might be.

Methodology: Type of Study and General Design: A double-blind study will be conducted with two randomly selected groups of firefighters; those who are to consume one 16 ounce Rockstar Punched ® brand EB and then perform a standard treadmill exercise routine and a control group, which will first consume a placebo beverage (PB) and then perform an identical exercise routine. The PB consists of a 50/50 mixture of club soda and water (16 oz total) and one Crystal Light Fruit Punch ® brand drink mix, which is both sugar and caffeine free. During the study period participants will refrain from consumption of any other beverages.

In order to establish baseline levels for all participants, each will first be asked to supply their age, weight, and an estimate of the average number of EBs and average number of caffeinated beverages consumed daily. Subjects will next be evaluated for urine specific gravity (SPGR), urine output (U/O), resting electrocardiogram (ECG), blood pressure (BP), heart rate (HR), total body water (TBW), intracellular fluid (ICF), extracellular fluid (ECF), and body mass index (BMI).

Subjects will then consume either 16 ounces of the EB or PB, wait 60 minutes (performing only minimal physical exertion, such as reading), at which time they will be evaluated again for the same parameters. They will then participate in a uniform 30 minute treadmill exercise routine, targeted to between 70% and 85% of the maximum heart rate (based upon age). Immediately after completion of the exercise and again 1 hour after exercise they will be evaluated for the same parameters.

A second identical evaluation will be conducted by switching the study and control groups, with the study group first consuming a PB and the control group first consuming an EB. A minimum 48-hour washout period will be utilized to ensure all remaining EB has been eliminated from the original study group.

Universe of study, sample selection and size, unit of analysis and observation: It is believed that this research will add to the general body of knowledge pertaining to firefighter health and safety, and more precisely to the literature pertaining to hydration and cardiac health, both of which have been found to have a direct impact on health and safety. For purposes of this research the target sample size is 25 participants.

Proposed Intervention: During the study phase test participants will be randomly selected and instructed to consume one popular, commercially available EB over the course of a 30 minute period. A control group will be instructed to hydrate with a placebo beverage (PB).

Inclusion & Exclusion Criteria: Firefighters from San Diego North County fire agencies will be invited to participate. Only firefighters assigned to regular suppression duties will be included (not on light duty or other work-restricted assignments). Selection will be made of healthy firefighters assigned to regular, unrestricted fire suppression duties who do not have known health or personal belief restrictions to the consumption of EBs or caffeinated beverages. Pregnancy and presence of a pacemaker are exclusion criteria as these conditions affect the accuracy of BIA measurements. All participants have recently completed full annual wellness evaluations which include a stress treadmill ECG. All participants will be asked to refrain from consuming EBs 48 hours prior to the test period but may otherwise consume beverages normally.

Firefighters who are assigned to a firefighting assignment during the study period will be excluded or asked to repeat the study after a waiting period.

Data collection procedures, instruments used, and methods for data quality control: Four methods of measurement will be utilized, with three readings to be taken. First, all participants will be weighed at the beginning of their work shift while wearing exercise clothing. Secondarily, a urine specific gravity and urine output will be obtained by utilizing FDA approved for home-use standard urinalysis dip test strips (URI1017), manufactured by CLIAwaived.com (San Diego, California). Third, resting electrocardiogram (ECG) and vital signs will be obtained and last, a bioimpedance analysis (BIA) will be conducted. The electrocardiogram (ECG) will be obtained utilizing a Lifepack 12® monitor/defibrillator. As the purpose of this research is to evaluate the presence of cardiac arrhythmias and not myocardial ischemia per se, it is believed that a 12-lead ECG is not warranted. Participants will consume either 16 ounces of water or an EB and wait 1 hour, after which they will again be evaluated for the same parameters. They will then participate in a 30 minute exercise upon a treadmill, immediately after which they will again be evaluated for the same parameters. One hour after termination of the exercise routine these same parameters will be measured for a fourth and final time, after which they will be questioned regarding their subjective physical feelings experienced during the study.

In order to ensure proper application of Bioimpedance analysis (BIA) instruction was received directly from the manufacturer on its use, maintenance, troubleshooting, and identification of error. BIA has been validated against other body composition methods and in healthy adults (Schneider, 2009). Participant data and BIA analysis will be collected by an individual familiar with use of a BIA device. In order to obtain reliable results tests will be conducted during the same time of day. Bioimpedance analysis is an easy to use, portable and non-invasive tool for use in the assessment of body composition parameters. The electrical impedance of the body is measured by introducing a small alternating electrical current into the body and measuring the resistance. Since muscle mass contains electrolytes, the greater the resistance measured, the greater the dehydration (Schneider, 2009). For purposes of this study the percentages of total body water (TBW), intracellular fluid (ICF), extracellular fluid (ECF), and body mass index (BMI) will be measured. The BIA device to be utilized for this experiment is the ImpediMed SFB7® utilizing the ImpediMed® dual tab electrode (part number IU02GELTD). These electrodes have a fixed 5 cm spacing from mid-point to mid-point of the electrode gel to assist with accurate and consistent placement. Normal ranges for TBW, ICF, ECF, and BMI (Schneider, 2009) as follows:

1. TBW: formula based upon age, weight, and sex
2. ICF 52-62% of TBW
3. ECF 38-48% of TBW
4. BMI 19-24.9

Procedures to Ensure Ethical Considerations in Research with Human Subjects: Known Risks and Benefits. As with any research involving the consumption of foods, persons with known or suspected hypersensitivity to EBs and/or their key ingredients will be advised that they may experience the reported side effects of these beverages. Specifically, at the time of entry into the study each participant will be provided with a brochure that describes the following: the objectives and purposes of the study, any experimental procedures, any known short- or long-term risks, possible discomforts, expected benefits of the procedures used, duration of the study, suspension of the study if a finding is made of negative effects or if there is sufficient evidence of positive effects that do not justify continuing with the study, and the freedom of subjects to withdraw from the study whenever they want. A signed agreement to participate in the study will be obtained from each participant.

Participants will receive no direct compensation for participation in the study. All participants' personal information will be kept strictly confidential as they will be directly monitored by the research evaluator. All results will be retained in a secure database available only to the research evaluator. Only common EBs for sale in the United States will be used for study purposes. Participants may provide their email address in order to obtain a copy of the study findings. Pregnant participants will be excluded as their levels of hydration are fundamentally affected by their pregnancy and the BIA device being utilized has not been calibrated to obtain reliable results from pregnant subjects.

As the basis for this study is heat stress and cardiovascular events experienced during wildland firefighting, which requires an "arduous" level of physical ability (as established by the National Wildfire Coordinating Group or NWCG), a level of exertion equivalent to the "pack test" was selected (Whitlock & Sharkey, 2003). This test consists of a 3 mile hike on level ground carrying a 45 lb. pack within 45 minutes. As a treadmill was utilized for this study this level of exertion was correlated to be equivalent to a 3.5 mph walking pace at a 5-10% grade (Sharkey & Davis, 2008, p. 8). To maintain this level of physical ability the authors recommend aerobic exercise 3 times a week. The Centers for Disease Control (CDC) recommends that target heart rates for aerobic exercise are between 70-85% of maximum heart rate, which is calculated as 220-age (CDC, 2011). In order to ensure safety of the participants, the Borg Rating of Perceived Exertion scale (RPE) was utilized (Borg, 1998). A RPE of 14-17 is consistent with an "arduous" level of exertion and achieves an aerobic level of exercise (Glencoe, 2008).

Plan for analysis of results: Inasmuch as the goal of this experiment is to evaluate real-world working conditions of firefighters, we are proposing a double-blind crossover test design. Given the prevalence of caffeinated beverages and the potential for their pre-test consumption to affect research results, this design has been selected to moderate for their effects upon the test and control groups. All participants will be randomly assigned to one of two groups. Additionally, they will be asked to provide their age, sex, and weight as each of these factors can affect hydration levels.

Timetable: It is anticipated that the entire study can be completed within a 6-month period from the point at which all program approvals are in place and all appropriate measurement equipment has been obtained.

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Appendix B

Energy Beverage Research Study

Participant Consent Form

You are being asked to take part in a research study as part an Executive Fire Officer Program from the National Fire Academy. This research protocol has been reviewed by a review board, similar to an Institutional Review Board or IRB. We want you to know that:

1. Taking part in this research is entirely voluntary.
2. You may choose not to take part, or you may withdraw from the study at any time, without any penalty of any kind.
3. You receive no benefit from taking part. The research may give us knowledge that may help people in the future.

Some people have personal, religious or ethical beliefs that may limit the kinds of medical or research treatments they would want to receive. If you have such beliefs, please discuss them with the research team before you agree to the study. A summary of the research is provided next. A complete copy of the research protocol is available upon request. Before you decide to take part, please take as much time as you need to ask any questions and discuss this study with the research team, or with family, friends or your personal physician or other health professional.

The purpose of this research is to evaluate the health effects of energy drinks upon firefighters, with the goal of promoting firefighter health and safety and reducing fireline injuries and fatalities. Selection will be made of healthy firefighters assigned to regular, unrestricted fire suppression duties who do not have known health or personal belief restrictions to the consumption of energy drinks or caffeinated beverages. All participants will be asked to refrain from consuming energy drinks for 48 hours prior to the test period but may otherwise consume beverages normally. Firefighters who are assigned to a firefighting assignment during the study period will be excluded or asked to repeat the study after an appropriate waiting period. Pregnant participants will be excluded.

An experimental study will be conducted with two groups of firefighters who will be assigned to one of two groups by chance; those who are to consume one 16 ounce Rockstar "Punched" brand energy drink and a control group, which will first consume a similar drink with fewer ingredients. Each group will receive both an energy drink and an energy drink with fewer ingredients. Subjects will first be evaluated with a urinalysis, resting ECG, BP, pulse rate and cellular hydration via bioimpedance analysis (BIA). One hour after consuming the energy drink subjects will be evaluated using the same mechanisms. They will then participate in a uniform 30 minute treadmill exercise routine, targeted to produce 70-85 % of their maximum heart rate. Immediately after completion of the exercise and again one hour after exercise they will again be evaluated for the same vital signs. After a minimum of 48 hours participants will repeat this procedure, with each group then consuming the opposite beverage.

Participants who experience untoward side effects may cease participation at any time and will be directed to stop if any significant side effects occur. The most common side effects associated with energy drinks include those associated with caffeine consumption and include increases to heart rate, blood pressure, and mild agitation. More profound but less common side effects include hypertension, tachycardia, and/or cardiac arrhythmias. In the unlikely situation that any of serious vital sign changes do occur the subject would be asked to discontinue the exercise test immediately, lie down, and receive needed support to reverse side effects. Participants having sensitivities to any of the ingredients contained in energy drinks should not participate. The caffeine content of the test energy drink is roughly equivalent to two (2) cups of caffeinated drip coffee. In comparable studies consumption of similar quantities of caffeinated beverages followed by exercise rarely resulted in any profound side effects.

Standard written consent document language:

1. Confidentiality. When results of a research study are reported in medical journals or at scientific meetings, the people who take part are not named and identified. We will not release any information about your research involvement, except as may be required by law.
2. Policy Regarding Research-Related Injuries. Your employer will provide short-term medical care for any injury resulting from your participation in research here today. In general, no long-term medical care or financial compensation for research-related injuries will be provided but rather would be handled via the standard Worker's Compensation claims procedures.
3. Payments. There is no payment or compensation for participation in this study.
4. Problems or Questions. If you have any problems or questions about this study, or about your rights as a research participant, or about any research-related injury, contact the Principal Investigator, Stephen Abbott, 330 S. Main St., Fallbrook, CA 92028 @ 760-723-2016.
5. Consent Document. Please keep a copy of this document in case you want to read it again.

Participant Name (print)	Witness Name (print)
______________________________	___________________________
Participant Signature	Witness Signature
______________________________	___________________________
Date/Time	Date/Time

Appendix C

Subjective Physical Feelings Questionnaire

Instructions to rater: Upon completion of the study (after taking the 1-hour post-exercise measurements), please ask each participant the following questions and record responses on the Excel spreadsheet. A "0" indicates no or a negative response and a "1" indicates a yes or positive response.

1. During the study did you experience increased mental alertness?
2. During the study did you experience increased energy?
3. During the study did you experience increased anxiety or nervousness?
4. During the study did you experience increased physical "jitteryness" or palpitations?

Appendix D

Recommendations from Energy Drink Study to Health & Safety Committee

To: Health & Safety Committee

From: B/C Abbott

Date: June 6, 2011

Subject: Recommendations from Energy Beverage study

As a result of the Energy Beverage (EB) study conducted over the last several months there are a number of salient recommendations that need to be evaluated in greater detail by our Health & Safety Committee. Findings revealed provide the basis for a number of recommendations pertaining to EBs as they pertain to firefighting activities, fitness for duty, pre-employment physical examinations, rehabilitation, routine physical fitness, and maintenance of overall cardiovascular health. The following encompass those recommendations:

Overall hydration: Of the 23 NCFPD employees that participated in the study a full one-third (34%) were sufficiently dehydrated (>2%) that had they been assigned to a firefighting assignment their physical and/or cognitive performance would have been impaired. It is recommended that employees need to follow hydration guidelines for endurance athletes. During periods of routine daily activity, consuming 11 to 16 eight ounce glasses of water (2600 to 3800 ml) per day is sufficient, with one glass (250 ml) consumed each hour. Prior to exertion (e.g. assignment to a fire) that amount should be doubled, and 200-300 ml of water should be consumed during every 10-20 minutes of exercise (Casa et al., 2000). Sports beverages such as Gatorade will augment rehydration, particularly when high loss of electrolytes is anticipated. It is suggested that this recommendation be incorporated into the San Diego North Zone

Rehabilitation Policy and implemented by company officers specifically when our personnel are responding to long-duration fire assignments.

Strike team assignments: Many incident management teams (IMTs) are now prohibiting EB consumption while assigned to an incident. As this is a general safety order issued by the incident Safety Officer at the direction of the Incident Commander, NCFPD employees are obligated to obey, just as they would any other lawful order. As iterated in the North Zone Strike Team Policy failure to obey such orders is grounds for dismissal from the incident. As this is a relatively new topic it is suggested that a general statement be added to this policy that addresses EB consumption while on strike team assignments.

Caffeine consumption: Nearly half (48%) of NCFPD employees experienced a 1% or greater reduction in cellular hydration after exercise following consumption of an EB, which is significant. Limitation of caffeine consumption to less than the documented daily maximum threshold of 8.2 mg/kg is strongly suggested, based upon the findings of Ganio et al. (2007). Using the average pre-test weight of participants in this study, an 86 kg male would reach this threshold at approximately 700mg or one to two 8 oz cups of coffee and 2 EBs, or an equivalent combination. Individuals that are heavy coffee consumers (>4 – 8oz cups/day) would only require 1 EB to exceed this threshold. *Employees that exceed this threshold are creating a health condition that makes them unfit for duty, a condition in which supervisors are obligated to intervene*. Understanding that the aforementioned 8.2 mg/kg is a maximum threshold employees are encouraged to consume a maximum of 200-400 mg of caffeine daily, ideally not in combination with sugar-containing beverages (e.g. “low carb.” alternatives). It is recommended that the maximum guideline be included in NCFPD’s Substance Abuse Policy. NCFPD officers currently have the ability to enforce this policy under the General Rules & Regulations.

Pre-employment screening: Malignant hyperthermia (MH) is a runaway metabolic emergency that mimics heat stroke and can produce fatal outcomes, and has been associated with caffeine consumption in conjunction with moderate exertion. Caffeine is actually used to diagnose this condition. It is now believed that many previous heat stroke episodes experienced by athletes were in fact MH. This is a condition which can be screened for during lab analysis. It is therefore recommended that NCFPD include this element into pre-employment examinations, and should it be found to exist, require that prospective employees sign an agreement that prohibits caffeine consumption on duty. As this recommendation would be specific to NCFPD, which generally follows the pre-employment physical exam requirements outlined in NFPA 1582, it is suggested this requirement be added to the Medical Evaluation Policy.

Appendix E

Individual Energy Beverage Study Results and Recommendations

(Sample)

Thank you for your participation in the energy beverage (EB) study. Your efforts greatly aided in providing very useful information that will directly contribute to firefighter health and safety. The following is a synopsis of your individual participant findings as well as general recommendations. Should you desire more detailed results and recommendations may be provided to you upon request.

With regard to your specific findings, you were found to be 3% dehydrated at baseline. Additionally, EBs were shown to have a significant effect upon your hydration status. 21% of department personnel were found to be 3% dehydrated, which is significant. Dehydration greater than 2% causes impaired cognitive and physical performance and greater than 3% dehydration requires in excess of 24 hours of recovery. Consequently, your hydration was at a level that presented a health & safety concern for sustained physical exertion (e.g. firefighting).

Considering the short-term diuretic effects associated with caffeine, the delay in fluid absorption associated with glucose-laden beverages, and the delay in acclimating to physical exertion in hot environments, it is strongly suggested to restrict or eliminate EBs from your work environment. From a health and fitness maintenance perspective, based upon this study's findings and consistent with recommendations in the literature firefighters should limit themselves to 200-400 mg of caffeine per day while at work. From a practical perspective this would include a maximum of two EBs or one EB and one to two 8 ounce cups of coffee in a 24-hour period for a well hydrated individual who is a regular caffeine consumer and is acclimatized to the work environment.

To improve your level of baseline hydration, during periods of routine daily activity, consume 11 to 16 eight ounce glasses of water (2600 to 3800 ml) per day, with one glass (250 ml) consumed each hour. Prior to exertion that amount should be doubled, and 200-300 ml of water should be consumed during every 10-20 minutes of exercise, and sports drinks will aid in carbohydrate and electrolyte replacement. Furthermore, research evaluating the causative factors behind stroke and heart attacks reveal a high degree of association between dehydration and these events. The risk of having a heart attack during the early morning hours (6am to 12 noon) is nearly double that later in the day, and increases in blood pressure and clotting factors (both of which are directly affected by hydration) are believed to contribute to this increased risk. It is therefore recommended that hydration consist primarily of water and avoidance of diuretic and high energy beverages, as well as hydration with 8 to 16 ounces of water prior to sleep specifically to reduce the risk of stroke.

Appendix F

Recommendation to NFPA 1582 Committee

(Submitted by email to proposals_comments@nfpa.org)

As an element of an EFOP project evaluating the health effects of energy beverages (e.g. Red Bull, Monster, Rockstar, etc.), a review of the literature revealed a potential correlation between highly caffeinated beverages and malignant hyperthermia (MH). It is my belief that incorporation of a screening tool into routine pre-employment firefighter physical examinations for those susceptible to MH may reduce the potential for firefighters to experience this condition.

MH is a condition of hypermetabolism (runaway cellular metabolism) that can be life threatening and is typically associated with untoward medication reactions, to include caffeine. The symptoms of MH can closely mimic heat stroke, particularly in the pre-hospital setting, and is not uncommon in the wildland firefighting environment. Tucker and Dugas (2008) review 18 documented cases of heat stroke wherein, based upon the climatic conditions presented, in each case the victims experienced “a potential for heat loss that exceeded the amount of heat they would produce from exercise” (p. 3). Two of the cases involved healthy runners that experienced fully developed heat stroke like symptoms after 16 minutes of running in temperatures between 62-72 ºF. It is believed that previous episodes of MH may have been misdiagnosed as heat stroke. It is noted that certain individuals are predisposed to MH, which occurs through stimulating an increase in intracellular calcium, which in turn increases metabolism and core body temperature. Furthermore, agents that stimulate the sympathetic nervous system such as caffeine are known to have similar effects upon calcium channels. The authors conclude that heat stroke is perhaps a physiologic failure similar or related to MH rather than the result of environmental conditions per se.

Clearly many firefighting conditions mimic those encountered by endurance athletes as noted in the study by Tucker and Dugas (2008). As consumption of caffeinated beverages is on the rise, and caffeine has a mechanism of action similar to other medications that induce MH (Hopkins, 2000), there is perhaps an enhanced need to ensure we address this potential risk. The main candidates for testing for MH are those with a close relative who has suffered an episode of MH or has been shown to be susceptible. The standard procedure is the "caffeine-halothane contracture test", CHCT. A muscle biopsy is carried out at an approved research center, under local anesthesia. While clearly this test is neither appropriate nor cost-effective for routine pre-employment physical examinations, its inclusion into the NFPA 1582 standard should be considered so that evaluating physicians can at least be aware of this enhanced risk to firefighters and screen accordingly. At the very least future pre-employment physicals could include an inquiry into a family history of MH, which would then dictate further evaluation as deemed appropriate by the evaluating physician.

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