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Examination of two hydration protocols during simulated forced marching under acute heat stress

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EXAMINATION OF TWO HYDRATION PROTOCOLS DURING SIMULATED FORCED MARCHING UNDER ACUTE HEAT STRESS

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Abstract

The purpose of this study was to identify and compare the effects of ingesting either water or 6% solution of carbohydrates, electrolytes, and water on hydration status during simulated military road marching in hot environmental conditions. Five volunteer male subjects completed two 60 minute experimental trials exercising at a high intensity (RER .90-.95) in an improvised environmental chamber (29.7 $\pm$ .18ºC, 11.3 $\pm$ 2.13% relative humidity) in full army combat uniform carrying 18.18kg of equipment. Random assignment of either water or solution was completed prior to trial 1, and consumption of the unselected protocol was completed during trial 2. Variables monitored included heart rate, core temperature, stroke volume, bodyweight loss, blood pressure, and hematocrit. Statistical analysis using MANOVA resulted in no statistically significant differences between trials for these variables. Post 30min data demonstrate consistent trends towards water being more effective at maintaining physiological markers of hydration compared to 6% solution during 60 minutes of intense exercise in high heat.

Chapter 1

Introduction

The US Army's operational theater has changed greatly since 2001. Current operations occur predominately in the nation of Afghanistan. Soldiers deployed to this country often find themselves conducting operations in temperatures as high as 49.9 degrees C. Increased equipment loads such as body armor and supplies needed for long distance missions are commonplace. Soldiers routinely carry loads of twenty nine to fifty eight kilograms for distances of ten kilometers or greater. The burden of heavy load carriage in hostile climates presents a unique physiological challenge for soldiers and commanders.

A priority for soldiers operating under these conditions is maintaining adequate hydration. Scientists agree that fluid loss can lead to decreased performance and possibly heat injury by depleting the body of essential electrolytes and substrates (Montain, Latzka, & Sawka, 1999; Sawka, Young, Latzka, et al., 1992). This fluid loss is multiplied in soldiers whose clothing, equipment, and activities all increase the rate of fluid loss. Multiple studies are available examining the hydration requirements faced by soldiers under various heat conditions (Montain, Sawka, Caderette, et al., 1994; Mudambo, Leese, & Rennie, 1997). These studies placed soldiers under different conditions with or without equipment loads, and each tested different hydration protocols. The results and recommendations of these studies conflict with each other, as well as existing research on fluid replacement. Compounding this conflict is the lack of accurate simulation data of current conditions faced by soldiers in the field.

While existing research examines multiple scenarios soldiers may experience regarding high heat environments, data specific to conditions and loads currently being experienced are not available. Without specific data, current hydration guidelines, such as the US Military Fluid

Replacement Guidelines (Kolka, Latzka, Montain, & Sawka, 2003) may not be optimal to prevent dehydration in under these conditions. This study's purpose was to examine the effects of heavy load carriage in a hostile environment on soldier hydration status, and the ability of two different hydration protocols to prevent dehydration under these conditions.

- **Research Questions:**
  - Does a heavy load in hot environmental conditions cause detrimental central cardiovascular responses and elevations in core temperature
  - Which hydration strategy, water or a 6% carbohydrate/electrolyte solution is most effective at maintaining hydration status in soldiers operating under the above conditions?
- **Null Hypothesis**: There will be no difference in hydration status between water and a solution of 6% carbohydrate/electrolytes in soldiers conducting high intensity work in a hot environment.
- **Assumptions:**
  - The testing protocol is appropriate for variables being tested.
  - Subjects will be truthful with responses to medical history questionnaires
  - Subjects will follow testing parameters such as nutritional and fluid intakes before testing outside of the laboratory.
  - The climate chamber will adequately maintain the desired environment during testing.
  - Subjects will give full effort during testing.

- **Limitations:**
  - Subjects may not give maximum effort during the VO2 Max Tests.
  - Subjects may not provide truthful answers to medical history questionnaires
  - Subjects may not provide accurate feedback on hydration status.
  - Testing protocol may not simulate metabolic demands soldiers experience in the field.
- **De-limitations:**
  - Subjects will be limited to males between the age of 18-24 to represent the average age and sex of soldiers currently in combat
  - Subjects will be familiar with Army physical fitness requirements and demands.
  - Subjects will be graduates of basic training or equivalent military training programs.
  - Subjects will undergo familiarization with testing protocol to ensure total understanding before data collection begins.
  - Loads carried by subjects will be based on US Army standard load requirements for soldiers in combat.
  - All equipment will be US Army standard issue, ensuring uniformity among subjects
- **Definitions:**
  - **High Heat Environment-** Environment where temperatures are greater than or equal to 29^{o} Celsius.

- **Hostile Environment-** An environment that causes increased physiological stress on an athlete or soldier performing physical activity beyond the stresses imposed by the exercise itself.
- **Load Carriage-** a term describing the activity of carrying mission essential equipment on the soldiers' person using backpacks and load bearing equipment
- **Mission Essential Equipment-** equipment and supplies such as body armor, ammunition, food, water, etc. that is required to complete a mission
- **Cardiovascular Drift-** a physiological phenomenon that occurs during exercise as a result of dehydration. It is characterized by a decrease in stroke volume and mean arterial pressure and a concordant increase in heart rate.

Chapter 2

Review of Literature

Physiological sweating thresholds are relatively low, independent of the cause of the elevation in heat exposure. Simply sitting in the heat can cause individuals to begin sweating. It follows that playing a sport adds significantly to the likelihood of sweating. These stresses notwithstanding, understanding why we sweat and the effects of sweating on human performance are crucial to addressing heat stress in athletic populations such as military personnel. By better understanding the physiology behind the effects of dehydration, more efficient prevention protocols may be developed for athletes exercising in the heat.

Effects on Physical Work Capacity

Dehydration results in decreases in both physiological and neurological performance. These decreases have been widely documented across numerous populations and physical activities. Decreases in blood glucose and electrolytes, plasma volume, fluid reserve, decreased thermoregulatory function and neuroglycopenia are directly tied to decreased exercise performance (Ebert et al., 2007; Mudambo, Leese, & Renne, 1997; Montain et al., 1998; Montain & Coyle, 1992). Numerous studies have examined the effects of dehydration on various athletic populations and found that the negative influence of fluid loss on the aforementioned responses is consistent across any sport or discipline.

In 1966, the US Army initiated a study of the effects of dehydration on muscular work. F.N. Craig and E.G. Cummings designed a study titled, “Dehydration and Muscular Work”, where eight enlisted volunteers and one of the authors themselves completed a treadmill exercise protocol while in a state of dehydration. Subjects were divided into two groups N_1=6 and N_2=3 (Craig & Cummings, 1966). The protocol consisted of each subject conducting an initial exercise session to failure on the treadmill. Upon completion, they were then taken to a cot where they were exposed to hot air for a period of five to six hours to promote dehydration. The treadmill test was repeated once subjects were adequately dehydrated. During the exercise sessions, core temperature and metabolic work equivalent data were collected through VO2, tidal volume, heart and respiration rates. Group one received no water during session one. Room temperature water was available during the second trial, and subjects were encouraged to drink. Group two received about one L of water on day one, and on day two were encouraged to drink all they could to replenish sweat losses.

The data collected showed levels of dehydration from 2.8 to 5.6% body mass during water restriction, and 0.1 to 3.5% when subjects were encouraged to drink as much as possible (Craig & Cummings, 1966). Prior to the walking trials, heart rates, rectal and skin temperatures were all elevated. Each subject had a decreased oxygen uptake, and eight subjects had decreased walking times post-test. The conclusion reached by researchers was that dehydration in combination with heat stress had a significant effect on exercise performance (Craig & Cummings, 1966). Decreased stroke volume was present as a result of the noted significant dehydration experienced by all subjects. This in turn led to increased heart rates that were observed and the lower oxygen uptakes as a result of decreased cardiac output. Blood sugar, electrolyte levels, and plasma volume were briefly discussed, however they were not directly measured. This study demonstrated a link between loss of bodyweight as a result of dehydration and detriments in exercise performance.

In their study, “Dehydration in Soldiers during Walking/Running Exercise in the Heat and Effects of Fluid Ingestion During and After Exercise,” Mudambo et al. demonstrated a clear physiological link between dehydration and decreased exercise performance. The study was designed to examine the effects of 16km of walking/running in high heat on hydration status, as well as the effects of three different hydration protocols at preventing dehydration under these conditions. Eighteen male African soldiers were divided into three groups and completed three hours of exercise in 39^{o}C temperatures. Exercise consisted of 18km walking/running and negotiating various obstacles. Subjects' body-weight was measured before and after exercise, cumulative urine volume was collected and measured, and individual perceived exertion was measured each of the three hours of the protocol. Before exercise began a blood sample was taken and the experimental groups drank 200mL of their assigned solution of either dextrose/electrolytes or fructose/corn syrup solids (Mudambo, Leese, & Rennie, 1997). During the exercise session, blood was collected each hour as well as upon completion of the protocol. Body-weight was measured again and then a 3-hour rehydration period began. This procedure was repeated on four separate days with variations to the hydration protocol being the initial drinking only, extra fluid during exercise, no fluid during recovery, or extra fluid during exercise and recovery (Mudambo, Leese, & Rennie, 1997).

Data collected from the experimental procedures demonstrated dehydration as high as 7% BW when subjects received no fluid, and between 1.8 and 2.8% for the hydration protocols (Mudambo, Leese, & Rennie, 1997). During the session without additional water, four subjects were unable to complete exercise beyond the two-hour mark and exhibited extremely low blood glucose levels, muscle cramps, fatigue, disorientation, hematuria, anuria, and increased blood viscosity on venipuncture (Mudambo, Leese, & Rennie, 1997). All subjects experienced decreased blood sodium levels during and after exercise that were only mitigated when consuming electrolytes. Plasma volume decreased 17% when no fluid was consumed during exercise, and between 4 and 10% when consuming hydration protocols (Mudambo, Leese, &

Rennie, 1997). Subjects' perceived exertion when consuming no fluids was much higher, with complaints of increased thirst and fatigue as the session progressed (Mudambo, Leese, & Rennie, 1997). As exercise progressed, neuroglycopenia contributed to disorientation and confusion among many subjects which was reflected in blood glucose measurements between 2.2 and 2.8 mmol· 1.

The data collected by the aforementioned study regarding dehydration during exercise demonstrated a decrease in virtually all physiological markers of hydration. Large decreases in blood glucose concentration, plasma volume, elevated core temperatures, and neuroglycopenic symptoms were experienced by all subjects. These symptoms prevented many subjects from completing the exercise session, and also produced signs of central nervous system fatigue leading to decreased metal function in some subjects. These results reinforce the physiological impact that dehydration has on the body and exercise performance. This study examined many of the factors that can contribute to dehydration based performance loss as a group, so the question arises as to how much dehydration plays on an individual parameter. By looking at the effects of fluid loss on specific physiological parameters, their role in decreased exercise performance becomes clearer.

Cardiovascular Effects

The previous section demonstrates a significant reduction in performance in the heat. One significant cause of a reduction in work capacity may be from cardiovascular effects. Fluid loss has been linked to cardiovascular strain during exercise with concomitant decreases in aerobic performance. Montain et al. examined the effects of graded dehydration on hyperthermia and cardiovascular drift on endurance trained cyclists (Montain & Coyle, 1992). During four separate exercise sessions, subjects exercised at 62-67% VO2 max for two hours. The environmental conditions were 33ºC and 50% relative humidity and in conjunction with the selected exercise intensity ensured a high amount of heat storage by the subjects. Different hydration protocols were selected to illicit specific degrees of dehydration of 1.1, 2.3, 3.4, and 4.2% of body mass. Measured parameters included core temperature by rectal probe, cardiac out by computer based CO_2 rebreathing technique of Collier, sweat rate by change of bodyweight pre and post exercise and blood analysis comparisons from pre and post samples.

The results of this study were linear to the percent of bodyweight lost through sweating. At each progressive level of dehydration, heart rate increased, plasma volume and cardiac output decreased. Core temperatures at each level also were progressively higher (Montain & Coyle, 1992). The researchers concluded that cardiovascular drift is proportional to the magnitude of dehydration, with notable increases in perceived exertion with each level of fluid loss (Montain & Coyle, 1992). The increased cardiovascular strain exhibited by the subjects can be linked to the increased perception of fatigue (Montain & Coyle, 1992). Similar results were linked to reduced performance in a study by Ebert et al. who examined the effects of dehydration on cycling performance and time to exhaustion.

In their study titled, “Influence of Hydration Status on Thermoregulation and Cycling Hill Climbing,” Ebert et al. took eight well trained male cyclists and put them through a series of time to exhaustion trials. Subjects randomly consumed two different hydration protocols, consisting of a low level of 50mL and a high level of 300mL every fifteen minutes. Physiological parameters monitored were rectal and skin temperature, heart rate, pre/during/post exercise blood samples, pre/post body weight, and time to exhaustion. Subjects first completed a two hour sub-maximal ride at 53% maximal aerobic power. Upon completion they were dried off and weighed, then proceeded to conduct a simulated hill climb. Exercise intensity was set at 88% of maximal aerobic power, and subjects rode their own bikes positioned on a customized treadmill set at 8% grade. These factors were selected to result in a time to exhaustion of 10-30 minutes. Once exhaustion was reached, subjects were again dried off and weighed.

The results of the study found that subjects consuming the low protocol lost an average of 2.5% of their body weight during the sub-maximal ride and 3.6% upon exhaustion during the hill climb trial (Ebert et al., 2007). The high protocol group experienced a fluid gain during the sub-maximal ride and a total loss of 1.3% upon completion of the hill climb trail (Ebert et al., 2007). The low group had increased core temperatures and heart rates compared to the high group, 158bpm versus 146bpm and 38.9 versus 38.3°C, and lower plasma volume post exercise (Ebert et al., 2007). Time to exhaustion decreased by 28.6% in the low group and power output was also lower in comparison to the high group, 308 watts = versus 313 watts respectively (Ebert et al., 2007). Based on these results, the researchers concluded that aerobic power output is reduced with dehydration in cycling athletes. This can be attributed to the loss in cardiovascular and thermoregulatory efficiency shown in the low group as a result of a 3.6% loss in body mass from dehydration (Ebert et al., 2007). This study provides solid evidence for decreased cardiovascular performance as a result of dehydration and confirms theories presented by previously mentioned studies with similar results.

Effects on Muscular Performance

When considering aerobic performance during exercise, the cardiovascular system is only part of the equation. The muscular system must be functioning optimally for exercise to continue. While previously examined studies have looked at the cardiovascular strain and fatigue induced by dehydration during exercise, the muscular component also needs to be addressed. In their study titled, “Hypohydration Effects on Skeletal Muscle Performance and Metabolism: A P=MRS Study,” Montain et al. specifically examine the effect of dehydration on muscle endurance and strength.

Ten physically active subjects, 5 men and 5 women, completed two experimental sessions separated by one week. During the testing protocol, subjects completed 2-3 hours of both moderate intensity treadmill and cycling exercise in a hot room. During the euhydrated trial, water was provided during exercise and subjects were encouraged to drink for the duration of the session. In the hypohydrated trial, fluid was restricted to ensure a body weight loss of 4%. After each exercise session, subjects consumed with a standardized meal (400kcal; 70% carbohydrate) to minimize the likelihood of hypoglycemia and replenish a portion of glycogen metabolized during the dehydration protocol (Montain et al., 1998). Subjects received a minimum of three hours rest before conducting muscle strength and endurance tests to minimize the effects of hyperthermia. During the rest portion of the euhydration protocol, water was provided to the subjects, and during the dehydration protocol water was restricted to maintain the 4% fluid loss (Montain et al., 1998).

At the completion of the rest period, subjects then completed a single leg, knee-extension exercise to exhaustion while lying in a MRI system. Exercise tempo was set at thirty-seven contractions per minute in the 110-140^{o} range of motion (Montain et al., 1998). The amount of resistance was set to elicit fatigue in 4 to 5 minutes. Average power output was collected for all subjects and the point of exhaustion was defined as the point when power output declined below 20% of the average power output during the first minute (Montain et al., 1998). Muscular strength was measured by performing five second maximal voluntary isometric contractions at 110^{o} extension (Montain et al., 1998). Blood samples were collected at rest and during exercise and used to assess hydrogen ion concentration, muscle pH, and phosphorus ratios.

Results indicated that muscular endurance/time to exhaustion were reduced by $\geq$ 8% in twelve of nineteen trials and mean endurance was reduced by 15% (Montain et al., 1998). These data confirmed pilot work that showed a 17% reduction in muscular endurance with a 4-5% loss in body-weight (Montain et al., 1998). There was no effect of dehydration exhibited on maximal muscle strength. The researchers presented two possible explanations for the loss of muscle endurance when dehydrated. Altered muscle cell depolarization and changed in calcium release/uptake by the sarcoplasmic reticulum (Montain et al., 1998). Dehydration produces changes in ionic status of the t-tubular lumen adversely affecting the t-tubular charge movement and decreasing force production (Montain et al., 1998). This may also occur as a result of longer calcium transient time resulting in decreased calcium influx during depolarization. The second theory explaining the decrease in muscular endurance is an altering of central nervous system function under dehydrated conditions (Montain et al., 1998). While the researchers suggest that decreased neurological drive as a result of altered cerebral blood flow may be responsible for the decrease in endurance performance, they admit that such theories are beyond the scope of their study. This postulation provides an excellent opportunity to further examine dehydration's effect on the nervous system performance during exercise.

Effects on Cognitive Function

In the study, "Impact of Rapid Weight Loss on Cognitive Function in Collegiate Wrestlers," Choma et al. set out to examine the impact of rapid weight loss of 5% bodyweight on neurological function. This was in response to the practice of rapid weight loss by wrestlers before meets and due to the majority of weight lost being water and muscle glycogen, links between rapid weight loss and exercise induced hypo hydration can be inferred from the data. Twenty-nine male college aged males, fourteen wrestlers and fifteen controls were selected to participate in the study. Subjects were tested during three states: a baseline, after rapid weight loss, and rehydration. Testing included cognitive, mood, and blood profile and weight measurement tests for each condition. Cognitive testing measured visual attention, visuo-motor skills, attention span, and short term memory. To minimize any learning effect three different test batteries were used to ensure subjects received different tests each session.

Researchers found a 6.2% average loss of bodyweight among the wrestlers participating in rapid weight loss (Choma, Celeste, Sforzo, & Keller, 1998). Decreases in cognitive performance tests and mood surveys were seen when compared to baseline and control measures (Choma, Celeste, Sforzo, & Keller, 1998). After rapid weight loss, the wrestlers also exhibited lower blood glucose and increased hypoglycemic symptomology than control subjects (Choma, Celeste, Sforzo, & Keller, 1998). The researchers theorized that the effect of the rapid weight loss on cognition was related to changes in exercise behavior (decreased motivation) and reductions in blood glucose and overall blood volume. These symptoms can be found in exercise induced dehydration, and their effects on the individual are the same. They lead to decreased will to exercise and neuroglycopenia results in decreased cognitive function due to lack of adequate brain glucose. There was no exercise conducted during this experiment, so in order to examine this effect on exercise we can look at the work of Baker et al. in the study titled, “Dehydration Impairs Vigilance-Related Attention in Male Basketball Players.”

Baker et al. set out to examine the effects of dehydration on the neurological performance of male basketball players (Baker, Conroy, & Kenney, 2007). This is due to both the high sweat rates of basketball players, and the high mental demands of the sport (Baker, Conroy, & Kenney, 2007). Eleven skilled male basketball players were selected to participate in a series of six experimental trials under six different hydration states including: euhydrated while consuming a commercially available solution of 6% carbohydrate (CHO), placebo with electrolytes and no carbohydrates, and 4 dehydrated states starting a 1% and stopping at 4% body-weight lost. Upon reporting for each session, subjects were weighed and then entered an environmental chamber set at 40^{o}C and 20% humidity. Next they completed an interval walking protocol consisting of nine 15-min bouts of walking separated by 5-min of rest at 50% VO2 max. Subjects were weighed again during each rest period. During euhydration protocols, subjects drank enough to replenish sweat and urine losses, and during dehydration protocols fluid was restricted to achieve desired fluid loss percentage.

Upon interval protocol completion, subjects completed a fatigue survey followed by the test of variables of attention (TOVA). This computer based test is used to measure the subject's visual attention processing and attention levels (Baker, Conroy, & Kenney, 2007). Measured variables included: omission errors, impulsivity errors, mean correct response time, and accuracy scores. Upon completion of the TOVA subjects rested for 50 minutes before beginning a basketball skills test simulating an 80-min game with four 15-min quarters separated by 5 minute breaks and a 10-min halftime (Baker, Conroy, & Kenney, 2007). Fatigue surveys were administered at halftime and upon completion of the drills. Finally, 20-min after completing the skills test a final TOVA test was conducted.

The results led researchers to three conclusions: First, dehydration impairs vigilance-related attention performance (Baker, Conroy, & Kenney, 2007). Second, attention impairment is linked to athletes becoming more conservative with information processing and decision making (Baker, Conroy, & Kenney, 2007). Third, dehydration related decrements in performance are most pronounced in stimulus-frequent situations. The researchers concluded that these results correlated previous findings where dehydration, fatigue, and decreased cognitive function were related (Baker, Conroy, & Kenney, 2007).

Baker continued his work with hydration status and basketball athletes in a study titled "Progressive Dehydration Causes a Progressive Decline in Basketball Skill Performance." Seventeen adult basketball players between 17-28 years of age completed the same interval walking protocol in an environmental chamber to produce the desired percentage of dehydration. Subjects entered a temperature neutral room for a 70-min recovery period during which either water, 6% carbohydrate/electrolyte, or placebo/electrolyte was consumed. Core temperature, heart rate, and blood pressure were measured at 15-min intervals. Subjects were then moved to a gymnasium where they completed an 80-min skills test designed to simulate a fast-paced basketball game. Skills tested included: sprint speed, agility/lateral movement, explosiveness, shooting, and combinations of two or more of these skills. Performance measures included the total number of shots made both stationary and on the move, single maximum vertical jump, single repetitive vertical jumps, single and total defensive movement times, and total timed score for all timed drills. Researchers controlled the various hydration levels throughout the drill test by weighing the athlete at the end of each quarter and providing the appropriate amount of fluid at the time. At halftime and upon completion the athletes completed a fatigue survey.

The study found that a progressive decline in performance occurred as dehydration progressed from 1 to 4% (Baker, Dougherty, Mosuk, & Kenney, 2007). The point where overall performance reached statistical significance was 2% (Baker, Dougherty, Mosuk, & Kenney, 2007). During the skills test, heart-rate and core temperature were not significantly higher in the dehydrated protocol compared to the euhydrated protocol (Baker, Dougherty, Mosuk, & Kenney, 2007). Subjective fatigue scores during the dehydrated protocol exhibited significantly higher self-perception fatigue and physical well-being (Baker, Dougherty, Mosuk, & Kenney, 2007). This led the researchers to theorize that the decrease in skill performance was a result of dehydration's effect on cognitive function and perception of fatigue. They correlated this theory with existing research that examined the deleterious effect of fluid restriction on perception of fatigue and metal drive to exercise.

Together, these studies present a solid case for dehydration as a detriment to exercise performance, as well as a risk to the athlete's health. These physiological and neurological effects represent a clear need for hydration recommendations in order to both prevent the onset of these symptoms as well as protect the health of the athlete. In order to better understand and provide these recommendations, one must look at the research examining the amount of fluid loss being experienced by athletes, as well as the body's ability to rehydrate itself during exercise.

Sweat Loss Magnitude and Rate Effects

Sweat loss rates are greatly influenced by environmental conditions, activity type/intensity, and any equipment required by the athlete or individual. The selection of football players and military personnel is based on the similar nature of conditions faced by each athlete and equipment requirements of each population. These similarities help offset the extremely small body of research available on military sweat rates by including a similar and well researched population.

In the study titled, “Sweat Rates, Sweat Sodium Concentrations, and Sodium Losses in 3 Groups of Professional Football Players,” Godek et al. conducted an observational study of professional football players that were separated into three groups: backs and receivers, linebackers and quarterbacks, and linemen to determine if sweat loss differed athlete size and position. Sweat loss was accounted for by bodyweight measurements before and after practice sessions. Athletes completed two practice sessions per day in helmets, pads, and shorts or full pads. Each practice session lasted 2-2.25 hours and temperature average for data collection days was 25.9^{o}C.

Results showed that sweat rates ranged from 1.4L/hour to as high as 2.25L/hour and sweat sodium losses ranged from 642mg/hour to 6.7g/hour (Godek, at al., 2010). Total sodium losses on longer practice days were calculated between 2.3 to 30g/day (Godek, at al., 2010). Fluid consumption during practice replaced between 65.3 and 67% of fluid lost representing a dehydration percentage of 1.13 to 1.2% (Godek, at al., 2010). Variations in the above measurements were attributed to the body cross sectional area differences among players at various positions, as well as activity level and wind/heat exposure at those positions. These data show that in a temperature neutral environment of 25.9^{o}C, sweat losses of football players can reach as high as 2l/hour or greater while fluid consumption replaces slightly more than 60% of fluid loss (Godek, at al., 2010). This is due to the nature of the sport, body type of the athletes, and increased metabolic demands of the pads and equipment that are worn during practice and game play.

These data correlate to another study by Fowkes-Godek on the same population titled, “Sweat Rates and Fluid Turnover in Professional Football Players: A Comparison of National Football League Linemen and Backs,” (Godek et al., 2008). In a comparison of football linemen and backs/receivers, similar results were obtained during two-a-day practice sessions wearing full pads. Temperatures ranged between 19-25°C. Sweat rates for linemen averaged 2.3L/hour and for backs/receivers 1.4L/hour (Godek et al., 2008). Total sweat loss for both practice sessions was 6.8L/hour and 4.1L/hour respectively (Godek et al., 2008). Fluid consumption was higher among the linemen with an average of 2.03L/hour compared to 1.1L/hour for the backs and receivers (Godek et al., 2008). The conclusion of this study mirrored those of the previous study that sweat rates were high among both groups, and the added body mass of the linemen contributed to the increased sweat rate and fluid consumption. Both groups failed to replace the fluid and sodium losses during practice with the end hydration status being 1.1% dehydration for linemen and 1.06% dehydration for backs/receivers (Godek et al., 2008). These studies draw attention to the sweat loss experienced by football athletes, but need comparison to other non-load bearing athletic activities to determine if these sweat rates are significantly higher than normal.

A comparison between football players and cross country runners was conducted by Fowkes- Godek, Bartolozzi and Godek in their study, “Sweat Rate and Fluid Turnover in American Football Players Compared with Runners in a Hot and Humid Environment.” A total of fifteen collegiate athletes, ten football players and five runners participated in the study. All subjects reported to the lab day one of their football or running preseason training for baseline testing. They reported four times a day on days four and eight to give blood and urine samples to measure fluid turnover. Football players practiced twice a day for the duration of the eight day camp. The AM practice was in shorts, shoulder pads, and helmets, and the afternoon practice was in full pads. Practice duration each time was 2.25 hours. The cross country runners followed their normal training routine of running once or twice daily. The average daily temperature and humidity was 28.4°C and 64.9% in the morning and 34.5°C and 43% respectively.

Measurements collected on day one included subject anthropometric data and baseline blood samples. During the 4^{th} and 8^{th} day of training, sweat rates and fluid turnover data were collected during the athlete's practice sessions. During the practice sessions, fluid intake was carefully monitored for all athletes and all were encouraged to drink at every opportunity. Once practice was complete, subjects showered and reported to the lab for body-weight and urine sample collection. Estimated fluid replacement requirements were calculated at 130% of lost body-weight. The data collected during the duration of the study included sweat rate, sweat loss, fluid consumption, fluid replacement requirements, and changes in plasma volume, urine production and specific gravity. Data from both groups was compared for significance.

The results of the study demonstrated that sweat rate during morning practices and overall sweat rate was higher in the football players versus the runners (Godek, Bartolozzi, & Godek, 2004). Mean sweat rates were 2.14L/hour and 1.7L/hour respectively (Godek, Bartolozzi, & Godek, 2004). Fluid replacement recommendations were higher for football players at 12L/day versus 4.5L/day for the runners (Godek, Bartolozzi, & Godek, 2004). The researchers concluded that the average sweat rates of football players wearing equipment and practicing in the heat are consistently over 2L/hour (Godek, Bartolozzi, & Godek, 2004). Due to the physical stature of the football players, higher fluid consumption is possible ranging from 500 to 2500mL in a single practice. At sweat rates this high, sodium loss becomes a serious priority, as does preventing hyponatremia from high amounts of water consumption.

Effects on Core Temperature

The effects of full pads are not limited to increasing sweat rates. Football players are also extremely susceptible to higher core temperatures during practice and game play in both moderate and high temperature environments. Godek et al. found that when wearing both full and shell pad configurations, football players' average core temperature rose from 98.6-99.3 to as high as 103.9 degrees F during practice in a moderate temperature environment ($83.2^{o} \pm 2.8^{o}$F) (Godek, Bartolozzi, Berkholder, et al., 2006). These results are similar to another study in which Godek et al. examined core temperature in NHL players during pre-season practice sessions. In this case, core temperatures elevated from a resting level of $98.8 \pm .5$ to 102.2^{o}F in a short amount of time (Godek, Godek, & McCrossin et al., 2007). The increased core temperatures in both of these studies were related to the exercise intensity and more importantly the addition of the required pads and equipment the resulting restriction of heat dissipation.

Elevated core temperatures become important when one considers the environment in which the activity is occurring. An athlete is described as being in compensated heat stress when heat production matches heat loss (Farrell, Joyner, & Caiozzo, 2012). This correlates to a core temperature of 37.5^{o}C and an environmental temperature of 27^{o}C. When heat production exceeds heat loss, the athlete is in uncompensated heat stress (Farrell, Joyner, & Caiozzo, 2012). Core temperature is no longer stable and begins a rapid rise (Farrell, Joyner, & Caiozzo, 2012). Core temperatures of $\geq 38^{o}$C cannot be compensated for in an environmental temperature greater than 26^{o}C (Farrell, Joyner, & Caiozzo, 2012). It is documented that exhaustion will typically occur before a core temperature of 40^{o}C is achieved (Cheung & McLellan, 2004; Sawka, Latzka, & Montain, 2001). At the rate core temperature increases once the compensation threshold is surpassed, the athlete will reach exhaustion very quickly if exercise continues. This is due to the body pulling fluid and cardiovascular volume away from the skin surface in order to maintain cardiac output. Evaporative cooling stops and core temperature rapidly climbs as cutaneous circulation decreases (Alonso, Rodriguez, Below et al., 1995).

Elevated core temperatures, combined with the effect of uncompensable heat stress increases the possibility of cardiovascular and central fatigue becomes a serious possibility. These studies demonstrate extremely high sweat rates and core temperatures among football and hockey players wearing equipment in the heat. Military populations, with similar or greater equipment requirements should exhibit similar physiological responses.

Dehydration in Military Populations

Military personnel conduct intense physical activity in temperatures as high as 49.9^{o}C (Afghanistan, 2012), often with equipment loads as heavy as fifty-eight kilograms (Beekly, Alt, Buckley et al., 2001). Montain, Latzka, and Sawka looked at both predicted and observed sweat rates in military personnel conducting various intensities of physical activity in the heat in their study, “Fluid Replacement Recommendations for Training in Hot Weather”. This study was unique in that before laboratory testing was conducted, computer models predicting sweat loss were used to gather pilot data, as well as validate the predictions of the software. Hydration guidelines generated from the computer models were then validated in through experimental testing.

During experimental testing twenty soldiers, fourteen men and six women first participated in a five day heat acclimatization protocol to minimize the effects of thermal adaptation on the test results. Subjects then participated in up to twelve exercise heat stress tests on a treadmill at three different intensities (250, 425, and 600W) representing easy, moderate, and hard work. Standard issue summer Battle Dress Uniforms and tennis shoes were worn during testing. Exercise tests were conducted in an environmental chamber where conditions were manipulated between three humid and three dry climates. Temperatures varied between 29^o and 46^{o}C and humidity was between 25-75%. Data collected during the testing protocol included rectal temp, indirect calorimetry to assess the metabolic cost of exercise, and pre/post body weights for sweat loss calculation.

The results of the study were presented in relation to heat conditions and work level. Sweat rates ranged from .38L/hour in lower temperatures to 1.13L/hour during the highest temperature conditions and low intensity work (Montain, Latzka & Sawka, 1999). Under medium work intensities, sweat rates ranged from .62L/hour to 1.1L/hour in (Montain, Latzka & Sawka, 1999). At high work rates sweat rates progressed from .79L/hour to 1.07L/hour (Montain, Latzka & Sawka, 1999). These data were an average of .5L/hour lower than computer predicted sweat rates. Data also revealed a linear relationship between temperature and sweat rates, as well as exercise intensity and sweat rates. In addition to quantifying sweat rates among soldiers during various heat conditions and work intensities, this study served as the basis for hydration recommendations that will be reviewed. It did however fail to replicate accurate conditions faced by soldiers in the field regarding the type/duration of the physical activity, as well as the clothing and equipment worn during the activity.

Lieutenant Colonels Ashkenazi and Epshtein examined alterations in plasma volume and serum protein in solders during s 110km march with a 20-kilogram load (Ashkenazi & Epshein, 1998). Twenty-two male subjects marched at 4.6-5.5km/h for twenty-four hours. Temperatures ranged from 17-32^{o}C with 45-85% humidity. No restrictions were placed on eating and drinking during the march, and all food or water consumed was recorded. Venous blood, urine samples, and body-weight were collected at three hour increments. Plasma volume, hematocrit, and serum total protein were measured from the blood samples, and sweat loss was calculated from pre and post exercise body-weight.

The mean sweat loss during the march was 3.4%, with a range of 2.7-5.0% of pre-march weights (Ashkenazi & Epshein, 1998). Plasma volume dropped significantly during and after the march, falling 6 and 8% respectively (Ashkenazi & Epshein, 1998). Researchers concluded that the dehydration resulted from voluntary dehydration limiting the subjects' ability to replace fluid losses. Fluid consumption during the march averaged 14.2L indicating a large amount of fluid being consumed during the exercise. This demonstrates that although subjects consumed large amounts of fluid, they still were not able to prevent dehydration. The average sweat loss of 3.4% is beyond the established 2% dehydration where decreases in performance are believed to occur (Sawka, Burke, Eichner et al, 2007). While no performance data were collected during the study, it can be reasonably assumed that there was a decrease in walking speed as dehydration increased.

This study provides two significant contributions: First, it provides a fairly accurate replication of physical activity that soldiers participate in. Second, it quantifies the significant sweat loss resulting from this activity. These results more accurately represent sweat loss experienced by soldiers while conducting physical activity under heavy loads.

The previously reviewed study by Mudambo et al. also documented sweat rates of subjects during the completion of the experimental protocols. Soldiers wore complete uniforms with combat boots. They also carried weapons, load bearing equipment, and backpacks for a total weight of 30kg. During the three-hour exercise period in the heat, soldiers experienced different sweat rates with the different hydration protocols that were used. When no fluid was consumed during testing, average fluid loss totaled 7% of body mass (Mudambo, Leese, & Rennie, 1997). With water consumption this number decreased to 2.8% of body mass (Mudambo, Leese, & Rennie, 1997). The dextrose/electrolyte solution loss was 1.8% and the corn syrup/fructose was 2.3% (Mudambo, Leese, & Rennie, 1997). While these results all differ due to the variance in the hydration protocols used, all demonstrated significant sweat loss and dehydration, especially when compared to the results of Montain et al. The results while receiving some sort of fluid more closely mirror the results obtained by Godek et al. from football athletes as well as Ashkenazi and Esphtein on soldiers on extended marches.

These studies demonstrate that when athletes are carrying equipment during physical activity or exercise in the heat, sweat demands are high. The sweat rate of soldiers carrying equipment during exercise mirrors that of football players during practice with pads. Establishment of this sweat rate range allows for selection of an appropriate hydration protocol.

Hydration Protocols

As a result of the above-mentioned study by Montain et al., the US military developed a hydration protocol to prevent dehydration among soldiers during exercise in various high heat environments. “US Military Hydration Guidelines” (Kolka, Latzka, Montain & Sawka, 2003) is a protocol that prescribes fluid recommendations based on the perceived work level and environmental conditions.

Soldiers conducting moderate to intense work in high heat should consume 1qt/hour and no more than 12qts/day of water based on these guidelines. Consumption limits are strictly emphasized to prevent hyponatremia. This fluid choice actually conflicts with other recommendations that are available (Sawka, Burke, & Eichner, 2007). Currnetly this guideline serves as the primary method reference for military personnel regarding hydration.

The next hydration protocol of interest is the ACSM Guide for Exercise and Fluid replacement. This protocol is based on consumption of a solution containing 6% carbohydrates and electrolytes during exercise (Sawka, Burke, & Eichner, 2007). The consumption rate is based on a percentage of weight lost during activity, and during activity individuals are encouraged to drink as much fluid as possible without gastric distress (Sawka, Burke, & Eichner, 2007). Also, included with recommendations during exercise are pre-exercise guidelines promoting super hydration to prevent dehydration. Inclusion of carbohydrates is recommended due to research showing improved endurance as a result of exogenous carbohydrate oxidation as well as increasing willingness to hydrate due to improved taste. (NATA, 2000; Coyle & Montain, 1992). Sodium is encouraged due to research, including multiple sources discussed previously, showing decreased plasma sodium with sweat loss. The National Athletic Training Association has also released a position statement regarding athlete hydration that mirrors that of the ACSM position above. They encourage pre, during and post hydration of the athlete as well as a similar consumption rate of 200-300mL during every 10-20 minutes of activity (Coyle & Montain, 1992). The solution recommended is identical to that of the ACSM, consisting of 6%carbohydrate and .3-.7g Na per L of water (Coyle & Montain, 1992).

A single study is available comparing these two protocols in a military population , conducted by Carvalho et al. and titled, “The Influence of Water Versus Carbohydrate-Electrolyte Hydration on Blood Components During a 16km Military March.” Twenty-six male soldiers were divided into two groups, one group consuming water, and the other consuming a lemon flavored beverage containing 60g/L of carbohydrates and electrolytes. All subjects received a high carbohydrate breakfast. Subjects carried 20kg of equipment and walked at an average pace of 5km/hour for 16km. They were instructed to consume 200 to 250mL of their respective beverage every fifteen minutes, equaling the maximal gastric emptying rate of ~1L/hour. Blood samples were obtained pre and post march, as were body weight measurements. Environmental conditions were 21-29^{o}C and 69-92% humidity.

The results of the study showed little difference among all measured variables between the carbohydrate/electrolyte and water groups (Carvalho et al., 2007). The small differences may be a result of: 1) high carbohydrate breakfast, 2) low sweat rates due to low exercise intensity and low ambient temperatures, or 3) super hydrated states as a result of the tested protocols. The large breakfast provided before the march contained 107g of carbohydrates which would sufficiently fuel the proceeding exercise (Carvalho et al., 2007). Low sweat rates and fluid loss could be related to exercise intensity and duration, as well as temperatures that started off low and only progressively got higher. Both hydration protocols produced super hydrated states post march indicating fluid intake greatly exceeding sweat loss.

We can see validation of the ACSM based solution in military personnel through Mudambo's research. When compared only water, the dextrose/electrolyte solution group demonstrated significantly better results across all measures of hydration status, as well as feeling of perceived exertion (Mudambo, Leese, & Rennie, 1997). Hydration loss in the solution group was 1.8% compared with 2.8% in the water group (Mudambo, Leese, & Rennie, 1997). Blood glucose concentrations were markedly improved during and post activity in the solution group as were plasma sodium levels (Mudambo, Leese, & Rennie, 1997). All of these data indicate that the dextrose electrolyte solution proved more effective at combating dehydration and extending the performance of soldiers in the heat.

In addition to superior sweat loss replacement, substrate depletion is also an issue during long duration physical activity (Sawka, Burke, & Eichner, 2007). Captain Paul Henning outlined the increased metabolic demands of military load carriage in the current theatre. He states that as the loads increase, more stress is placed on both the glycolytic and oxidative energy systems (Henning & Khamoui, 2012). This increased metabolic demand results in a much higher use of glycogen (Henning & Khamoui, 2012). This elevated substrate use coupled with repeated bouts load carriage and compromised nutritional status can result in rapid depletion of glycogen and electrolyte stores. It becomes evident that a hydration protocol providing exogenous carbohydrates and electrolytes during activity is more suitable than simply water as it provides fuel for the activity and prevents fatigue due to endogenous glycogen depletion (Sawka, Burke, & Eichner, 2007).

The negative effects of dehydration are well documented, as are the sweat loss rates and increased core temperatures experienced by different populations of athletes while exercising in the heat. While hydration recommendations are well researched for civilian athletes, there is a lack of research comparing available hydration protocols in military populations. The existing research is insufficient at replicating conditions faced by soldiers as well as exercise intensities and equipment carried during exercise. There is a clear need for more research accurately representing these conditions in order to provide soldiers with the best hydration recommendations possible.

Chapter 3

Methods

Subjects

Fourteen cadets from the Marshall University ROTC program initially volunteered for the study. Of these fourteen, eight participated in initial VO_2 Max testing. Seven began experimental trials. Six completed both experimental sessions. Two subjects were injured during activity outside of the study and could not complete their second trial. The final subject was dropped due to being unable to complete the 60 minute exercise session. Descriptive data for these subjects are presented in table 1 as group means ± standard deviation.

Age	Height (cm)	Weight (kg)	VO_2 Max (ml/kg/min)
20.6 ± .89	177.2 ± 11.28	79.89 ± 17.77	52.24 ± 3.94

Table 1. Subject Descriptive Data

The study received approval by the Marshall University Institutional Review Board. Written informed consent was obtained prior to testing and the form is included as Appendix B. A heath screening questionnaire was completed to determine inclusion and is included as Appendix C

Experimental Design

Subjects underwent initial VO_2 max testing, followed by two experimental testing sessions of one hour in length. During each experimental trial, subjects consumed either water based protocol, or an ACSM based 6% solution of carbohydrates, electrolytes, and water at an identical rate of 250mL every 15 minutes. Subjects were randomly assigned to either the water based protocol, or the ACSM hydration protocol. Based on this assignment, subjects reported to the lab and completed a testing session using the assigned protocol. Following a 7 day washout period, subjects reported back at the same time to repeat testing with the other hydration protocol.

Protocol and Procedures

Improvised Environmental Chamber

Experimental sessions were conducted within an improvised environmental chamber. The room was lined with sheets of plastic across the ceiling secured with two inch adhesive tape. Primary heating was provided by a 1000 watt infrared space heater capable of maintaining a constant temperature of 26.7 degrees Celsius. Supplemental heating was provided by an electric radiator. The intent of this secondary source was to provide additional heat above the 26.7 degree maximum of the infrared heater in order to reach the target temperature range of 29.5 to 30.5 degrees Celsius. Any modification of room temperature once the 26.7 degree constant was reached was accomplished through manipulation of the secondary heat source. Room temperature during experimental trials was 29.7 $\pm$ .18 degrees Celsius. Humidity averaged 11.3% $\pm$ 2.13.

VO2 Max Testing

Subjects reported to the laboratory at a prescheduled time wearing normal athletic clothing and in a well hydrated state. They were instructed to refrain from consuming alcohol, caffeine, or any other supplements the day prior to and of testing. Testing was conducted on a Quinton Med Track ST55 Treadmill and metabolic measurements obtained with a Metabolic Measurement System (Parvo Medics True 2400 Metabolic Measurement System – Nonlinear CO2). After being familiarized with the testing procedures, subjects were fitted with a Polar heart rate monitor (Polar Electro, Inc. Salt Lake City, UT), head and mouth piece for metabolic testing, and prepared for the graded exercise test.

Subjects sat stationary for 3 minutes prior to the test in order to allow for stabilization of normal breathing and heart rate patterns. Upon completion of this three minute period, the test began. After a four minute warm up period, speed was set at 6mph and grade at 0%. Speed remained constant while grade was increased 1.5% each minute until the subject reached volitional fatigue. VO_2 and related gas exchange measures were determined over 15 second intervals, and heart rate was collected at 1 minute intervals. The VO_2 max obtained for each subject was used later to calculate cardiac output and stroke volume, which were needed to assess cardiovascular drift. Initial VO_2 max testing was performed under normal laboratory conditions with temperature and humidity averaging 21.3 degrees C and 18.5%

Experimental Trials

Subjects arrived at the laboratory after following the same pre-test instructions used during the VO2 max testing. During these sessions, subjects reported wearing the Army Combat uniform and worn in combat boots. Urine specific gravity was measured to determine if subjects had arrived in an euhydrated state (USG < 1.030) (Fisher Scientific/Midget Urinometer c/n 22-274-209,Thermo Fisher Scientific Inc., Waltham, MA). Subjects measured their nude bodyweight, placed on a Polar hear rate monitor, and inserted a rectal temperature probe (PhysTemp RET-1, Physitemp Instruments, Inc., Clifton, New Jersey) 8-10cm past the anal sphincter. Subjects were then seated upright while pre-test blood pressure was measured. A blood sample was obtained by capillary lancing of the subject's left index finger. The sample was used to measure resting hematocrit levels (Hemopoint H2, EKF-diagnostic, Germany). Also during this time subjects were fitted to the Metabolic Measurement System (Parvo Medics True 2400 Metabolic Measurement System – Nonlinear CO2) and temperature monitor (PhysTemp

BAT-10, Physitemp Instruments, Inc., Clifton, New Jersey). Resting heart rate and core temperatures were recorded.

Subjects were familiarized with the new testing procedure prior to the session start. Hydration protocol was randomly selected by the subject by drawing either a 1 (Water) or 2 (Solution) written on folded slips of paper out of a non-see through plastic container. Metabolic data were collected during experimental session 1 to determine the speed and grade necessary to achieve steady state exercise at a high intensity, but sustainable rate of work. This was operationally defined as a RER of .9-.95 while the ventilatory equivalent remained stable. This was maintained for 5 minutes after speed and grade were no longer increased. Testing began at a walking speed of 3.3mph and 0% grade. Speed remained constant while grade was increased every minute until a RER of .9-.95 was observed. At this point, exercise intensity was maintained for 5 minutes to ensure that the subject had achieved the desired steady state intensity. After steady state was verified, the head/mouth piece and nose clip were removed, and metabolic data collection ended. During the second experimental trial, changes in speed and grade were mimicked from the subject's first session, but no metabolic data was collected using the Metabolic Measurement System.

Subjects were stood up and loaded out with the equipment required for the simulated march. This included a military issue load bearing vest (LBV), and ruck sack containing the predetermined packing list, attached as Appendix D. The total weight of the equipment was 18.14 kg (40lbs). All subjects used the same equipment maintained at the laboratory to ensure compliance with load requirements.

Heart rate and core temperature measurements were taken every minute. Room temperature was measured every five minutes in order to allow for temperature adjustment as needed, as well as to provide mean temperature data for the session. At fifteen minute intervals blood pressure measurements were taken. This measurement was taken with minimal disruption to the exercise. Subjects consumed prescribed fluid protocol at the rate of 250ml/15min. The drink was provided in a 1000mL graduated Nalgene bottle (Nalgene, United States). The bottle was pre-marked with permanent ink at the desired 250mL intervals. Testers ensured that subjects consumed the prescribed amount at each interval. Two more blood samples were obtained at thirty and sixty minutes through capillary lancing of different fingers to collect hematocrit measurements.

Experimental trials one and two were separated by 7 days to provide a washout from any adaptation to the experimental environment conditions. Testing procedures for trial two were identical to those described for trial one with the exceptions of using the hydration protocol not used during trial one, and collection of metabolic data.

Safety was constantly monitored during each experimental trial. Due to the high environmental temperatures and exercise intensity, core temperature was constantly monitored and testing terminated if subjects exceeded a core temperature of 39.5 degrees for longer than 3 consecutive minutes. This was based on research showing that core temperatures between 38-40 degrees C lead to central fatigue and increased risk of heat injuries such as heat stroke. Subjects were also encouraged to provide feedback as to perceived exertion. This included information such as gastric upset and dizziness.

subjects completed a five minute cool down period which began after final blood pressure measurements were taken. Equipment loads were removed, and the room was opened to provide cool air and circulation. Subjects obtained their nude bodyweight and removed the rectal probe and heart rate monitor once the cool down period was completed,. The rectal probe was sterilized using a hospital grade disinfectant and placed back in it protective container.

Subject A-V o_2 difference (C(a-vDo2) ml/100ml) was calculated through the regression equation, y = 5.72 + .10*x, where y is equal to C(a-vDo2) ml/100ml and x is the percentage of subject $VO_{2\ max.}$ This equation was generated and validated by Stringer, Hansen, and Wasserman in their study, "Cardiac Output Estimated Noninvasively from Oxygen Uptake During Exercise."(Stringer, Hansen, & Wasserman, 1996). C(a-vDo2) ml/100ml was then inserted into the Fick equation for cardiac output where CO= VO_2(ml/min)/C(a-vDo2)*100. Cardiac output was used in conjunction with heart rate to determine stroke volume through the equation CO= HR*SV. Stroke volume and heart rate were used to assess cardiovascular drift occurring as a result of dehydration during exercise

Statistical Analysis

Statistical analysis was performed using SPSS v.17 for Windows (SPSS, Inc., Chicago Il.) Data are reported as means $\pm$ SD unless specified otherwise. A repeated measures multiple analysis of variance (MANOVA) was used on the following data: pre/post bodyweight, core temperature, heart rate, stroke volume, and systolic/diastolic blood pressure to test for significance between the two trials. Significance was set at .05. Descriptive data for group means were created using Microsoft Excel. Individual descriptive data were generated and are included by subject number as Appendix E.

Chapter 4

Results

Results of the MANOVA are listed in table 2 (see below).

Dependent Variable	Type III Sum of Squares	df	Mean Square	F Ratio	Significance
Heart Rate	59.290	1	59.29	0.185	0.709
Stroke Volume	59.614	1	59.614	2.009	0.292
Core Temperature	.048	1	0.048	0.385	0.598
Hematocrit	.360	1	0.36	0.031	0.876
Systolic blood pressure	29.160	1	29.16	0.153	0.734
Diastolic blood pressure	3.240	1	3.24	0.253	0.665
Bodyweight	.275[g]	1	0.275	0.245	0.669

Table 2. MANOVA Data Table

Fluid Volume Changes

Subjects experienced a bodyweight decrease of 1.87kg (80.38 ± 17.63 to 78.51 ± 17.11) during TW. TS bodyweight loss was 1kg (79.42 ± 17.87 to 78.42 ± 17.59). Between subject effects were not statistically significant (F=0.245), p < 0.669. Hematocrit levels during TW increased 6% (43.2 ± 4.2 to 49.2 ± 2.2). An increase of 3.2% was observed in TS (43.6 ± 1.5 to 46.8 ± 1.6). Percent increase comparison was not statistically significant (F= .031), p < 0.876. Blood pressure during TW decreased from 170.4 ± 5.4/66 ± 13.1 to 133.2 ± 3.1/56 ± 10.4. TS experienced a reduction from 173.4 ± 9.34/67 ± 9.97 to 135.8 ± 3.49/58.8 ± 3.11. Comparison of these reductions was not statistically significant (Systolic BP F=.153, Diastolic BP F=.253), p < 0.734, p < 0.665.

Central Cardiovascular Effects

Heart rate during TW increased 21 ± 6.3 beats per minute (bpm). An increase of 25.2 ± 4.55 bpm was observed during TS. Between trial comparison of these increases was not significant ($F=.185$), $p<0.709$. Stroke volume was reduced by 14.5 $\pm$ 6.3mL (2.9% reduction during TW, and 15.7 $\pm$ 4.55mL during TS. These results were not statistically significant ($F=2.009$), $p < 0.292$. Core temperatures increased 1.16 $\pm$ .403^{o}C (TW) and 1.52 $\pm$ .415^{o}C (TS). Statistical comparison was not significant ($F=.385$), $p < 0.598$.

Chapter 5

Discussion

Statistical analysis of the data collected produced no statistically significant results. That does not dismiss the significant physiological changes observed within all subjects during both experimental trials. These trends provide insight into differences in each hydration protocol's ability to maintain hydration and exercise performance. Through discussion of these data, recommendations may be made concerning practical application of hydration strategies.

Fluid Volume Changes

Sweat Loss

Decreases in subject body weight was observed in both the water trial (TW) and solution trial (TS). The mean weight loss observed during TW of 1.86kg, or 2.3% bodyweight (BW) is greater than the 1kg, (1.2%) BW loss observed in TS. This observed difference between the water and solution based hydration protocols was also documented by Carvalho et al. who documented an average weight loss of .62% for their water group and .09% for their solution based group (Carvalho, Marins, & Garcia, 2007). The authors attribute the low levels of dehydration in both groups to the subjects being adequately hydrated and acclimatized to the environmental conditions. While prior acclimatization to high temperature environments does reduce sodium losses during exercise, sweat loss is actually initiated at lower core temperatures (McArdle, Katch, & Katch, 2014). This leads to increased sweat loss due to its initiation at a lower core temperature. It is more likely that the lower intensity of exercise and variable climate conditions observed during the study were not strenuous enough to evoke a greater sweating response.

Mudambo et al. observed a 2.8% and 1.8% BW loss within their water and solution groups. Subjects in this study exercised in an environment where ambient temperatures were consistently elevated (30°C) and exercise intensity was also high. A possible explanation for the increased sweat loss observed in the water groups of both this study; and those cited above is delayed gastric emptying of the solution based protocol. The addition of carbohydrates to water increases the gastric emptying time of fluids from the alimentary tract (Brouns, Senden, Beckers, & Saris, 1995). It is possible that when drinking the solution, subjects absorbed water at a slower rate compared with water consumption. This results in a decreased sweat rate as less fluid would be available for sweating. It also leads to decreases in plasma volume and cardiac output, and increases in heart rate and core temperature. All of these effects were observed in this study and will be discussed later.

It is generally accepted that exercise induced dehydration of $\geq$ 2% of BW results in decreased aerobic exercise performance (Sawka, Burke, Eichner et al, 2007; Cheuvront, Carter, & Sawka, 2003). These studies provide the basis for position stands of the ACSM and NATA on hydration protocols for athletes exercising in the heat. When this dehydration level is applied to subjects within this study, a discrepancy arises. TW experienced a 2.3% mean decrease in bodyweight during the exercise session. This implies that performance should have decreased. However, physiological markers of dehydration such as cardiac output, stroke volume, and core temperature were better maintained by TW when compared to the TS data that indicated a mean BW loss of 1.8%. Recently completed research will provide insight into why the 2% dehydration level may be an incorrect indication of decreased aerobic performance.

In his 2012 meta-analysis, Goulet found that exercise induced dehydration of up to 4% BW did not decrease aerobic exercise performance in cyclists. Subjects within the studies included in the meta-analysis experienced BW losses ranging from 1-4%. Instead of decreasing performance, these fluid losses lead to a marginal .06% increase in endurance performance (Goulet, 2012). Zouhal et al. reinforced this with data on 643 marathon runners in which a significant linear relationship was found between magnitude of BW loss and race finish time (Zouhal et al, 2011). Sharwood et al. and Kao et al. found similar relationships between BW losses and finish times in triathletes and ultra-marathoners (Sharwood et al., 2004; Kao et al., 2008). These data indicate that losses of bodyweight up to 4% may not be causative of decreases in exercise performance.

Hematocrit

Hematocrit levels for both protocols increased from pre-testing levels at the 30 minute measurement. This linear increase for both trials separated during the 30 minutes between the second measurement and post-test measurement. Figure 1 (see below) demonstrates that TW hematocrit levels continued to rise, reaching a group mean of 49.2% while TS began to decline, reaching a group mean of 46.8%.

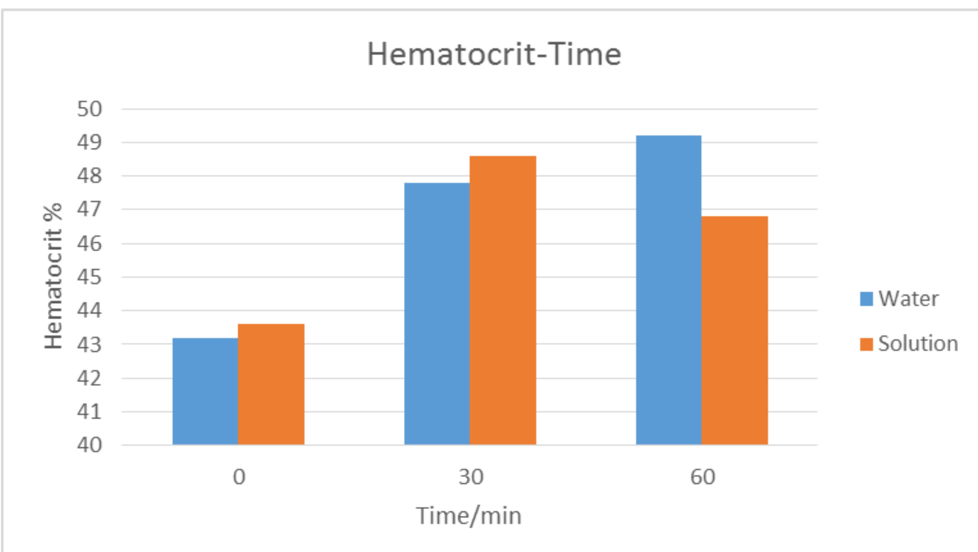

Figure 1. Hematocrit Comparison between Trials

The observed hemo-concentration experienced by both groups from baseline to 30 minutes is correlated with a decrease in plasma volume due to water loss through sweating. The continued increase in TW is indicative of continued reductions in plasma volume during exercise. A plausible physiological explanation for the reduction in the hematocrit could not be found. The high hemoconcentration level may have exceeded to capability of the Hemopoint H2 monitoring system owing to aberrant values

The only means of increasing plasma volume would be to rehydrate the individual at a greater rate than sweat loss was occurring. Consumption rate was set a 1L per hour, 250mL/min. This consumption rate is aligned with the maximum gastric emptying rate of $\pm$ 1 L/hr. Subjects during testing were sweating at a rate exceeding both the consumption rate and gastric emptying rate. Restoring plasma volume during the 30 minutes between measurement T-30 and T-60 would not be possible.

Central Cardiovascular Effects

As heart rate increases, stroke volume decreases due to decreased diastolic filling time. This effect is expected when exercise intensity increases, as during a graded exercise test. During this study, exercise intensity was kept constant once subjects had achieved a RER of .95. Since a physiological steady state exercise was maintained because the external work was unchanged, the heart rate would theoretically stabilize with an expected, but slight, cardiac drift. A significant upward trend in heart rate occurred during both experimental trials without an increase in exercise intensity. These increases were met with a concomitant decrease in stroke volume as the tables below demonstrate. This phenomenon, called cardiovascular drift, is a well-documented response to dehydration during exercise in high temperature environments (Montain & Coyle, 1992; Wingo, Lafrenze, & Ganio et al., 2005). As dehydration reduces plasma volume through water loss heart rate is elevated in order to maintain the required cardiac output for the exercise. Central cardiovascular changes in the present study are displayed in Tables 3 and 4 (see below.

	Water		Solution	
Subject Number	**HR Increase (bpm)**	**% Increase**	**HR Increase**	**% Increase**
1	15	7.8	22	11
2	21	13.1	27	16.2
3	18	9.8	19	10.1
4	25	16.2	30	18.1
5	26	16.04	28	16.3
Group Means	21 ± 4.64	12.6 ± 3.74	25.2 ± 4.55	14.3 ± 3.55

Table 3. Heart Rate Increase Comparison within Trials

	Water		Solution	
Subject Number	**SV Decrease Water (mL/beat)**	**% Decline**	**SV Decrease Solution**	**% Decline2**
1	9.4	7.8	13.1	11.0
2	16.8	11.6	19.5	14.0
3	7.4	9.0	7.3	9.2
4	23.1	14.7	23.5	15.3
5	16.0	13.4	15.3	13.6
Group Means	14.5 ± 6.3	11.3 ± 2.9	15.7 ± 6.2	12.6 ± 2.5

Table 4. Stroke Volume Decrease Comparison within Trials

Wingo et al. reported similar cardiovascular drift data during submaximal aerobic exercise in cyclists (Wingo, Lafrenz, & Ganio et al., 2005). During their 45 minute experimental trial, subjects lost a mean of 3.7% BW, experienced a 12% increase in heart rate, and a 16% decrease in stroke volume. The environmental conditions during tests were 30°C and 40% relative humidity; conditions similar to those used during this study (29.5°C mean temperature, 18% relative humidity). During $VO2_{Max}$ testing performed immediately after the 45 minute testing period, subjects experienced a mean $VO2_{max}$ decrease of 19% (Wingo, Lafrenz, Ganio, et al., 2005). These bodyweight losses, decreases in stroke volume, and increases in heart rate are similar to observations from this study. Figure 2 (see below) shows the drift occurring in each trial based on group means at 15 minute intervals.

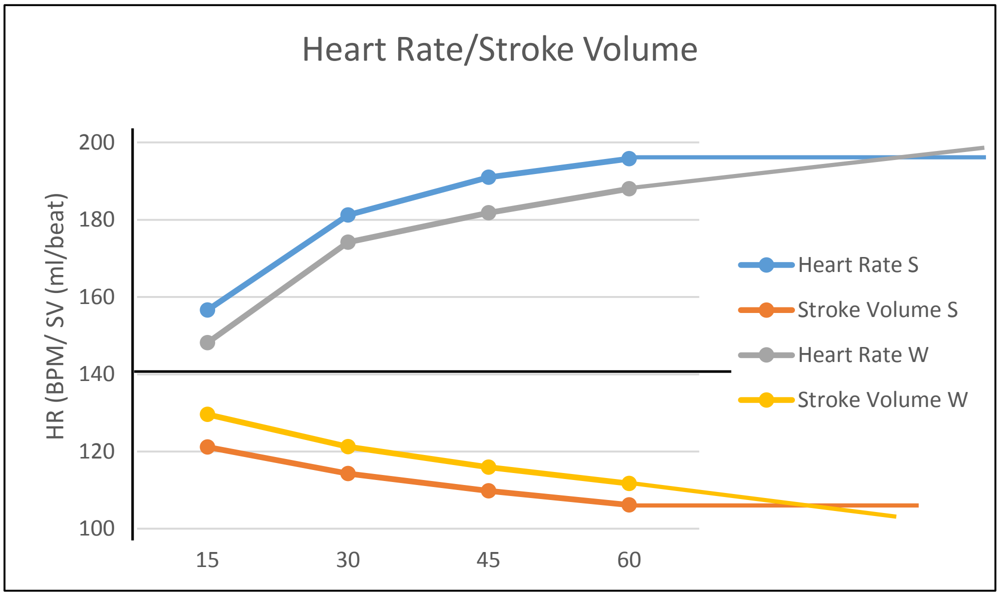

Figure 2. Heart Rate/Stroke Volume Comparison

TW was able to better maintain stroke volume with an 11.3% reduction compared to TS at 12.6%. TW also had a lower increase in HR at 12.6% compared to a 14.3 % increase in TS. Based on the data obtained from Wingo et al., both experimental trials would have seen a reduction in VO_2Max. TW would have experienced less loss of performance due to the lower HR increases and SV losses.

It is also important to point out the heart rates recorded in TS at T-45 and T-60 as they are close to or exceed the group predicted max heart rate of 193bpm. These higher heart rates would reduce the cardiovascular system's ability to compensate for further reductions in stroke volume as subjects were at or close to their maximum heart rate. TW would have a longer time interval until this compensatory limit was reached due to the lower observed heart rates at the same time points. If the trend lines above were extended out at their current slopes, TW would eventually intersect TS indicating that subjects had reached their maximum heart rates. The amount of time it would take TW to intersect TS represents more time at which the subjects of this study could exercise at a higher intensity before requiring rest, or reaching failure and being unable to continue.

Visual and subject reported levels of perceived exertion support the higher heart rates found in TS. Individuals unanimously favored water consumption over solution. They reported greater perceived exertion while consuming solution and visually appeared to be working harder. Two individuals reported light headedness, and a concern of possibly passing out. These qualitative measures help to support the physiological indications that subjects would have reached exercise failure sooner if exercise had continued beyond 60 minutes while consuming the solution.

Core Temperature

Increases in core temperature (T_C) were observed in both experimental trials. The results are displayed in table 5 (see below).

	Water		Solution	
Subject Number	CT Increase (Deg C)	% Increase	CT Increase (Deg C)	% Increase
1	0.9	2.3	1.6	4.1
2	0.6	1.5	0.8	2.0
3	1.6	4.1	1.8	4.5
4	1.4	3.53	1.8	4.54
5	1.3	3.3	1.6	4.04
Group Mean	1.16 $\pm$ .403	2.946 $\pm$ 1.04	1.52 $\pm$ .415	3.844 $\pm$ 1.03

Table 5. Core Temperature Changes within Trials

A rise in T_C was expected due to the exercise intensity and ambient environmental conditions. Under normal exercise conditions, T_C will gradually increase and plateau after thermoregulation is accomplished. In our testing conditions, the environmental stress, coupled with the work intensity, and progressing dehydration resulted in a linear increase for the duration of testing.

This resulted in TW and TS reaching 39.1 and 39.48°C respectively. Graphical representation of these T_C changes may be found in figure 3 (see below).

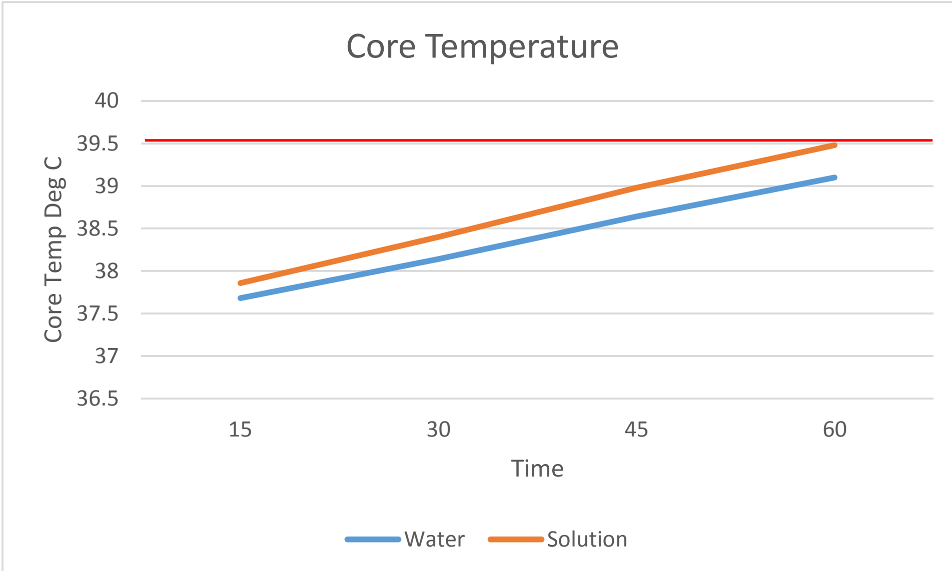

Figure 3. Core Temperature Changes within Trials

Exercise exhaustion and risk of heat injuries such as heat stroke are associated with core temperatures of ~40°C (McArdle, Katch & Katch, 2010). Alonso et al. confirmed this assertion by examining core, muscle, and skin temperatures in physically conditioned individuals cycling in high temperature environments. They found that exercise exhaustion occurred at a T_C of 40.1-40.2°C, and that time to reaching this temperature was directly related to the rate of heat storage (Alonso, Teller, & Andersen et al, 1999). The rate of reaching these core temperatures was directly related to time to exhaustion, indicating that when higher core temperatures were reached gradually versus acutely, individuals were able to exercise longer. These data provide valuable insight into the above core temperature data.

Table 6 (see below) lists individual T^C measurements for each subject in 15 minute intervals. T^C was markedly higher in each subject from T-30 to completion.

	Water					Solution			
Subject	**15min**	**30 min**	**45 min**	**60 min**	**Subject**	**15min**	**30 min**	**45 min**	**60 min**
1	37.4	37.8	38.2	38.5	**1**	37.5	38	38.7	39.3
2	38.1	38.2	38.4	38.8	**2**	38.2	38.6	38.7	39.2
3	37.7	38.3	39	39.5	**3**	37.7	38.3	39.1	39.7
4	37.6	38.3	38.9	39.6	**4**	38.2	38.7	39.3	39.6
5	37.6	38.1	38.7	39.1	**5**	37.7	38.4	39.1	39.6
Mean	37.68	38.14	38.64	39.1	**Mean**	37.86	38.4	38.98	39.48

Table 6. Individual Core Temperature Changes

The rate at which subjects reached these temperatures was also greater in TS versus TW. Figure 4 (see below) indicates that the temperature for TS was increasing at a greater rate than TW with a slope of .0363 compared to .0317.

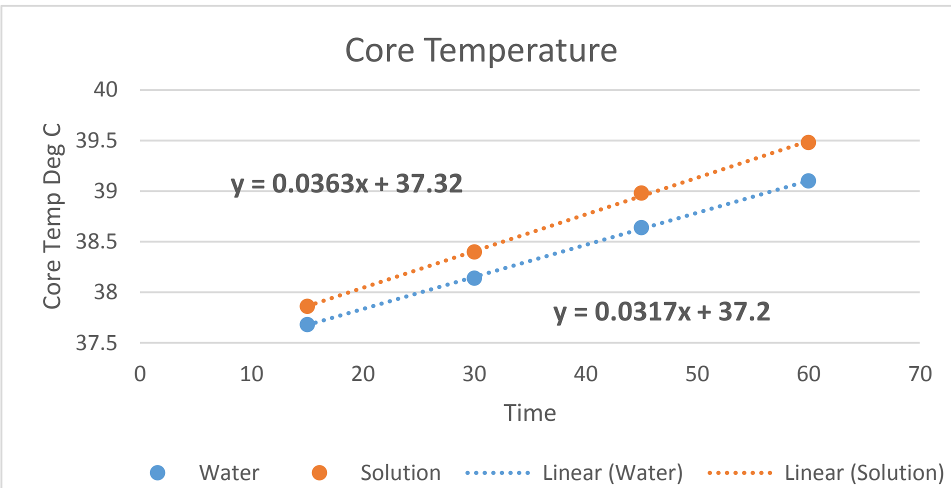

Figure 4. Core Temperature Rate of Increase Comparison

The separation between trials became evident after the T-30 measurement point. It is possible that delayed gastric emptying of TS, which may have reduced sweat rates due to reduced water being available for sweating, caused a reduction in evaporative cooling capacity through sweating. This would result in core temperature increasing at a greater rate. Alonso et al. observed that as core temperatures increase and cardiovascular drift increases, systemic and cutaneous vascular resistance increases (Alonso, Rodriguez, Below et al., 1995). They attributed this to increased norepinephrine release intended to elevate heart rate and maintain blood pressure in response to reductions in plasma volume. By decreasing blood flow to the skin, exchange of warmer blood from the core with cooler blood of the skin would be reduced. This would keep warmer blood in the core of the body, increasing heat storage and rate of temperature increase.

The lower T_C and rate of increase within TW could be a result of multiple factors. Water may have been leaving the digestive tract faster, providing water for sweating and therefore evaporative cooling. By better maintaining cardiac output and stroke volume owing to better gastric empting, the thermoregulatory responses that favor maintaining cardiovascular function will therefore be deferred, allowing more cutaneous skin profusion and evaporative cooling. These data indicate that TW reduced the rate of increase in core temperature in comparison to TS. As a result of this lower rate of increase, individuals operating at high intensity in the heat would be able to do so longer before heat exhaustion becomes a significant risk.

Blood Pressure

Blood pressure measurements from both trials demonstrate the reductions characteristic of reductions in plasma volume. As the magnitude of dehydration increased across exercise time, blood pressure dropped. Tables 7 and 8 (see below) display group means for measurements collected at 15 minute intervals from the start of exercise to session of exercise.

Trial Water Blood Pressure Measurements								
Subject	**15 minutes**		**30 minutes**		**45 minutes**		**60 minutes**	
1	168	78	141	66	138	65	134	61
2	176	81	155	79	140	75	130	70
3	176	61	140	58	135	45	131	48
4	164	50	150	40	138	40	133	44
5	168	60	157	58	144	58	138	57
Mean	170.4	66	148.6	60.2	139	56.6	133.2	56
STDV +	5.366563146	13.09580085	7.829431652	14.18449858	3.31662479	14.32829369	3.1144823	10.36822068

Table 7. TW Blood Pressure Measurements

Trial Solution Blood Pressure Measurements								
Subject	**15 minutes**		**30 minutes**		**45 minutes**		**60 minutes**	
1	189	74	164	70	145	63	136	61
2	168	81	153	70	141	65	138	62
3	171	61	150	58	137	55	131	54
4	174	61	160	58	138	59	134	59
5	165	58	155	58	140	51	140	58
Mean	173.4	67	156.4	62.8	140.2	58.6	135.8	58.8
STDV +	9.343446901	9.974968672	5.594640292	6.57267069	3.1144823	5.727128425	3.492849839	3.1144823

Table 8. TS Blood Pressure Measurements

While there was no statistical difference between trials at each point, figure 5 (see below) shows that TS had slightly higher systolic and diastolic measurements at each time point.

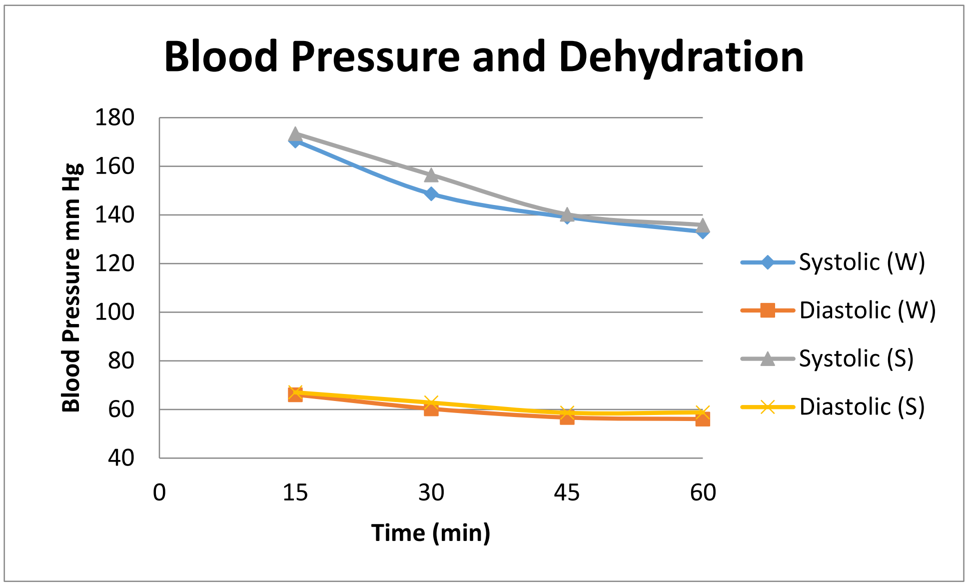

Figure 5. Blood Pressure Comparison between Trials

These slight differences may be attributed to increase sympathetic drive in an effort to maintain cardiac output (Alonso, Rodriguez, Below et al., 1995). Alonso et al. observed that as dehydration increased, there was a reactive vasoconstriction in the skin. They attributed this to increased catecholamine release aimed at redirecting cutaneous blood flow back into central circulation (Alonso, Rodriguez, Below et al., 1995). It is also possible that the small observed differences may be tester variability of measurement.

Conclusions/Recommendations

When planning military operations, the most important component of consideration is called the "no later than" time. This point represents the latest time that a mission must be completed to be successful and facilitate future operations. If one piece of a strategic battle plan is not completed, the whole operation may fail. Mission commanders must consider all variables that may impact this time line and make adjustments and control measures for each. This includes ensuring that soldiers possess a means of hydration adequate for the mission timeline.

The data from this study suggests that when planning operations with a high intensity demand and a timetable of one hour or less, water is the better choice. During the 60 minutes of intense exercise in our high heat environment, water better maintained stroke volume, core temperature, and heart rate. It has been demonstrated in previous research that a more controlled rate of increase with these variables allows for delayed time to exhaustion and increased exercise performance. Within the environments and intensities that soldiers are currently operating, dehydration and physical strain are unavoidable. A more effective approach to hydration is selection of a protocol that extends time until these variables reach the point of causing exhaustion. By selecting water, commanders may provide soldiers with the ability to operate more successfully under these conditions.

Results obtained by this study provide some interesting and exciting possibilities for future research into soldier hydration requirements. The primary focus of this study was short duration, high intensity operations. While this represents a part of the total operational scope of today's military forces, many missions also have longer time tables that can last hours or days. More research is needed looking at timelines beyond the 1 hour point with variable exercise intensities and load carriage requirements. Examination of solutions containing only added electrolytes are also needed as they provide a possible means of electrolyte and fluid replacement without the gastric distress experienced with a carbohydrate solution.

The null hypothesis is accepted for this study. The consistent trends for the discrete data collected leads me to conclude that the variance was sufficiently maximized but the number of subjects precluded significance. From a practical and tactical standpoint the physiological differences in the data collected leads me to conclude that under short duration, high intensity operations in high temperature environments, water is the more effective hydration solution compared to a 6% carbohydrate/electrolyte mixture. The results obtained herein support the use of the US Military Hydration Guidelines as an effective hydration strategy for operations under conditions similar to those within this study.

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Appendices

Appendix A

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Office of Research Integrity
Institutional Review Board
401 11th St., Suite 1300
Huntington, WV 25701

FWA 00002704

IRB1 #00002205
IRB2 #00003206

March 18, 2014

Terry Shepherd, Ph.D
Marshall University, Department Exercise Physiology

RE: IRBNet ID# 535519-2
At: Marshall University Institutional Review Board #1 (Medical)

Dear Dr. Shepherd:

Protocol Title: [535519-2] Preventing Dehydration during Military Operations in the Heat: A comparison of two established hydration protocols on cardiovascular drift during exercise in the heat.

Expiration Date: January 8, 2015
Site Location: MU
Submission Type: Revision APPROVED
Review Type: Expedited Review

The above study was reviewed at the January 8, 2014 full board meeting of the Marshall University Institutional Review Board #1 (Medical) and approved pending modifications for the period of 12 months. The Chair has reviewed the submitted revisions: 1) in the abstract changed "Primary" to "Principal" after the principal investigator's name and 2) corrected the word "Principle" to "Principal" on page 4 of the contact information in the informed consent. The approval will expire January 8, 2015. Continuing review materials should be submitted no later than the deadline for the December 10, 2014 IRB agenda.

If you have any questions, please contact the Marshall University Institutional Review Board #1 (Medical) Coordinator Trula Stanley,MA, CIC at (304) 696-7320 or stanley@marshall.edu. Please include your study title and reference number in all correspondence with this office.

Appendix B

Marshall	Approved on:	3-18-14	University IRB
	Expires on:	1-8-15	
	Study number:	535519	

Informed Consent to Participate in a Research Study

Preventing Dehydration during Military Operations in the Heat:

A Comparison of Two Established Hydration Protocols

Dr Terry Shepherd, Principal Investigator

David Cottrill, Co-investigator

Dr. Suzanne Konz, Co-investigator

Introduction

You are invited to be in a research study. Research studies are designed to gain scientific knowledge that may help other people in the future. You may or may not receive any benefit from being part of the study. Your participation is voluntary. Please take your time to make your decision, and ask your research investigator or research staff to explain any words or information that you do not understand.

Why Is This Study Being Done?

The purpose of this study is to examine two hydration protocols, the US Military Hydration Recommendations and the American College of Sports Medicine Guidelines for Fluid Replacement, and their ability to prevent dehydration during strenuous physical work in a high temperature environment. This research will address the need for soldiers and commanders to have the most effective hydration recommendations available while conducting operations and training in high temperature conditions.

How Many People Will Take Part In The Study?

Ten to twenty people will take part in this study. Twenty subjects are the most that would be able to enter the study.

What Is Involved In This Research Study?

During this study, subjects will complete seven exercise sessions. The first five sessions will be acclimatization sessions to prepare participants for high heat exercise. The final two sessions will be the experimental testing sessions. Sessions will be 1 hour in length while in a high temperature (32 degrees Celsius/89.6 degrees Fahrenheit), environmentally controlled room. During these sessions, volunteers will be required to wear complete Army Combat Uniforms and a prescribed amount of combat equipment weighing 65lbs to simulate current conditions faced by soldiers currently deployed to Afghanistan.

The tested elements in this study are the two hydration protocols. Volunteers will complete one exercise session while following the Military Recommendations for Fluid Replacement, followed by a 72hour recovery period. Volunteers will then complete one final exercise session while following the American College of Sports Medicine recommendations for fluid replacement.

During the exercise sessions, volunteers will be fitted with a rectal thermometer probe to measure core temperature. Metabolic data will be collected during exercise by using a metabolic measurement cart. This data collection requires volunteers to wear a headpiece and face mask. The face mask will be connected to a metabolic cart, by a flexible hose, extending to ventilation and gas analyzers that determine the content of exhaled air.

How Long Will You Be In The Study?

You will be in the study for about 2 weeks.

You can decide to stop participating at any time. If you decide to stop participating in the study we encourage you to talk to the study investigator or study staff as soon as possible.

The study investigator may stop you from taking part in this study at any time if he/she believes it is in your best interest; if you do not follow the study rules; or if the study is stopped.

What Are The Risks Of The Study?

There may be these risks:

- Participants will be conducting moderate to hard exercise in high temperature environments. Therefore the risk of complications from this exposure such as fatigue, light headedness, cramping, dehydration or more serious adverse effects such as heat stroke, or hyponatremia are possible risks. All possible precautions are in place to avoid these risks. Cardio pulmonary resuscitation/Automated external defibrillator certified personnel will be at every testing session. Physiological variables related to core temperature and hydration levels will be consistently monitored and safety limits are in place to prevent the above risks.

- The data collection and testing procedures explained above may result in discomfort and or irritation. Subjects should also expect to be exposed to high temperatures and the physical discomforts and responses typical of such exposure.

There may also be other side effects that we cannot predict. You should tell the researchers if any of these risks bother or worry you.

Are There Benefits To Taking Part In The Study?

If you agree to take part in this study, there may or may not be direct benefits to you. We hope the information learned from this study will benefit other people in the future. The data collected by this study will benefit military and first responder personnel that operate under heavy loads and high temperatures. Other benefits of participating in this study may be: guidance regarding the most appropriate hydration protocol for loaded walking or hiking in the heat. Also, you will learn about your current fitness level (VO2max).

What About Confidentiality?

We will do our best to make sure that your personal information is kept confidential. However, we cannot guarantee absolute confidentiality. Federal law says we must keep your study records private. Nevertheless, under unforeseen and rare circumstances, we may be required by law to allow certain agencies to view your records. Those agencies would include the Marshall University IRB, Office of Research Integrity (ORI) and the federal Office of Human Research Protection (OHRP). This is to make sure that we are protecting your rights and your safety. If we publish the information we learn from this study, you will not be identified by name or in any other way.

What Are The Costs Of Taking Part In This Study?

There are no costs to you for taking part in this study. All the study costs, including any study tests, supplies and procedures related directly to the study, will be paid for by the study.

Will You Be Paid For Participating?

You will receive no payment or other compensation for taking part in this study. In addition, no compensation will be given for injury sustained during data collection.

What Are Your Rights As A Research Study Participant?

Taking part in this study is voluntary. You may choose not to take part or you may leave the study at any time. Refusing to participate or leaving the study will not result in any penalty or loss of benefits to which you are entitled. If you decide to stop participating in the study we encourage you to talk to the investigators or study staff first.

Whom Do You Call If You Have Questions Or Problems?

For questions about the study or in the event of a research-related injury, contact the **study Principal investigator, Dr. Terry Shepherd at 304-553-9448**. You should also call the investigator if you have a concern or complaint about the research.

For questions about your rights as a research participant, **contact the Marshall University IRB#1 Chairman Dr. Henry Driscoll. His phone number is 304-696-7320** You may also call this number if:

- You have concerns or complaints about the research. o The research staff cannot be reached.
- You want to talk to someone other than the research staff.

You will be given a signed and dated copy of this consent form.

SIGNATURES

You agree to take part in this study and confirm that you are 18 years of age or older. You have had a chance to ask questions about being in this study and have had those questions answered. By signing this consent form you are not giving up any legal rights to which you are entitled.

____

Subject Name (Printed)

____ ________________

Subject Signature Date

____

Person Obtaining Consent (Printed)

____ ________________

Person Obtaining Consent Signature Date

Appendix C

Medical History and Present Medical Condition Questionnaire

Name: Date:

In order to determine your eligibility for this experiment, we encourage you to answer all of the following questions. If you are uncomfortable with answering a particular question, feel free to leave it blank. Please explain all YES answers at the end of this questionnaire.

PERSONAL MEDICAL HISTORY

Have you have ever had any of the following conditions?

YES	NO	
❑	❑	1. Allergies
❑	❑	2. Loss of hearing
❑	❑	3. Asthma
❑	❑	4. Kidney disease
❑	❑	5. Prostatitis
❑	❑	6. Colitis
❑	❑	7. Hepatitis
❑	❑	8. Liver disease
❑	❑	9. Elevated liver enzyme test
❑	❑	10. Pancreatitis

YES	NO	
❑	❑	11. Ulcer
❑	❑	12. Heart attack
❑	❑	13. Heart murmur
❑	❑	14. Positive stress test
❑	❑	15. Heart valve abnormality
❑	❑	16. Angina
❑	❑	17. Heart failure
❑	❑	18. High cholesterol
❑	❑	19. High blood pressure
❑	❑	20. Arthritis/rheumatism
❑	❑	21. Loss of consciousness

YES	NO	
❑	❑	22. Epilepsy
❑	❑	23. Convulsions/seizures
❑	❑	24. Stroke
❑	❑	25. Diabetes
❑	❑	26. Thyroid trouble
❑	❑	27. Anemia
❑	❑	28. Eczema
❑	❑	29. Cancer (including skin cancer)
❑	❑	30. Sleep apnea

REVIEW OF CONDITIONS

Do you currently have or have you recently had any of the following?

EYES, EARS, NOSE, THROAT

YES	NO	
❑	❑	31 Difficulty with night vision
❑	❑	32. Change in vision
❑	❑	33. Blurred or double vision
❑	❑	34. Bleeding gums
❑	❑	35. Frequent nosebleeds
❑	❑	36. Frequent sinus trouble
❑	❑	37. Recent hoarseness
❑	❑	38. Ringing/buzzing ears
❑	❑	39. Earaches

PULMONARY

YES	NO	
❑	❑	40. Shortness of breath
❑	❑	41. Chronic or frequent cough
❑	❑	42. Brown/blood-tinged sputum
❑	❑	43. Chest tightness
❑	❑	44. Wheezing

GENITO-URINARY

YES	NO	
❑	❑	45. Bladder trouble
❑	❑	46. Blood in urine
❑	❑	47. Irregular vaginal bleeding
❑	❑	48. Currently pregnant
❑	❑	49. Difficulty starting/stopping urination
❑	❑	50. Urinating 3 times per night
❑	❑	51. Frequent or painful urination
❑	❑	52. Problems with sexual function

GASTROINTESTINAL

YES	NO	
❑	❑	53. Vomited blood
❑	❑	54. Persistent diarrhea
❑	❑	55. Persistent constipation
❑	❑	56. Frequent abdominal pain
❑	❑	57. Frequent nausea
❑	❑	58. Frequent indigestion/heartburn
❑	❑	59. Black/bloody bowel movement
❑	❑	60. Hemorrhoids
❑	❑	61. Trouble swallowing
❑	❑	62. Hernia

CENTRAL NERVOUS SYSTEM

YES	NO	
❑	❑	63. Fainting spells
❑	❑	64. Recurrent dizziness
❑	❑	65. Frequent headaches
❑	❑	66. Tremors
❑	❑	67. Memory loss
❑	❑	68. Loss of coordination
❑	❑	69. Difficulty concentrating
❑	❑	70. Numbness/tingling extremities

HEART/VASCULAR

YES	NO	
❑	❑	71. Palpitation (irregular heartbeat)
❑	❑	72. Pain or discomfort in chest
❑	❑	73. High cholesterol
❑	❑	74. Swelling of feet
❑	❑	75. Leg pain while walking
❑	❑	76. Painful varicose veins

PERSONAL MEDICAL HISTORY

MUSCULOSKELETAL

YES NO

❑ ❑ 77. Back trouble/pain
❑ ❑ 78. Neck trouble/pain
❑ ❑ 79. Joint injury/pain/swelling
❑ ❑ 80. Carpal tunnel syndrome

MISCELLANEOUS

YES NO

❑ ❑ 81. Bleeding/bruising easily
❑ ❑ 82. Enlarged glands
❑ ❑ 83. Rashes
❑ ❑ 84. Unexplained lumps
❑ ❑ 85. Chronic fatigue

YES NO

❑ ❑ 86. Night sweats
❑ ❑ 87. Undesired weight loss
❑ ❑ 88. Snoring
❑ ❑ 89. Difficulty sleeping
❑ ❑ 90. Low blood sugar

ADDITIONAL HEALTH AND LIFESTYLE QUESTIONS

Please answer the following questions honestly:

YES NO

❑ ❑ 91. Are you experiencing any stresses, mood problems, relationship difficulties, or substance-related problems for which you would like resource or referral information on a confidential basis?

❑ ❑ 92. Do you occasionally use or are you currently taking any prescription or over-the-counter medications? List name, dosage, and the reason the medication is used on the next page.

❑ ❑ 93. Have you had any surgical operations in the last 10 years?

❑ ❑ 94. Has anyone in your immediate family developed heart disease before the age of 60?

❑ ❑ 95. Do any diseases run in your family?

❑ ❑ 96. Do you currently have a cold/cough, or have you had any in the last two weeks?

❑ ❑ 97. Have you ever been hospitalized? If yes, list date, length of stay, and reason on the next page.

❑ ❑ 98. Are you currently under a doctor's care? If yes, list what you are being treated for on the next page.

❑ ❑ 100. Have you had a change in the size or color of a mole, or a sore that would not heal in the past year?

❑ ❑ 101. Do you have any special concerns regarding your health that you would like to discuss with the doctor?

❑ ❑ 102. Are you a current cigarette smoker?
  A. How many packs of cigarettes do you smoke a day?
  B. How long have you been smoking?

❑ ❑ 103. Are you an ex-smoker?
  A. How many years did you smoke?
  B. How many packs a day?
  C. When did you quit?

❑ ❑ 104. Have you used chewing tobacco or smoked cigars/pipe in the last 15 years?

105. ________________________________ I drink ________________________ beers; ounces of hard liquor; ounces of wine per week.

106. When were your most recent immunizations?

Tetanus __________________ Flu shot __________________ Pneumovax ________________

107. When were you most recent health maintenance screening tests?

Cholesterol _______________ Results? __________________ PSA (Prostate) _______________ Results? ______________

Mammogram______________ Results? _________________ Sigmoidoscopy ______________ Results? ______________

Pap smear ________________ Results? _____________

108. Describe any hobbies or recreational activities that have exposed you to noise, chemicals, or dust:

---

109. Please describe typical weekly exercise or physical activities including any exercise at work:

---

110. My current diet could be best characterized as (check all that apply):
Low-fat ❑ Low-carb ❑ High-protein ❑ Vegetarian/Vegan ❑ No special diet

111. Do you have a history of heat illness or injury? Yes__ No__

Appendix D

The following equipment represents the load carried within the rucksack during the march.

A	Ruck Sack with Frame	B	Wet Weather Bag
C	2 Meals Ready to Eat (MRE)	D	Hot Weather Desert Boots
E	Running Shoes	F	MOLLE FLC Complete
G	1 Quart Canteen with Cup and Pouch	H	ACH complete (no cover/mounts)
I	ACU Top (x2)	J	ACU Bottom (x2)
K	Gortex or Field Jacket	L	PT Shirt (long Sleeve)
M	PT Shirt (short sleeve)	N	PT Shorts
O	PT Jacket	P	PT Pants
Q	Full Size Cotton Brown Towel (x2)	R	Patrol Cap
S	Reflective Belt or Vest	T	T-Shirt Tan (x3)
U	Poly Pro Top or Gen III Level 2 Top	V	AA Handbook (
W	Glove Inserts (1 pair)	X	Leather Work Gloves
Y	Watch Cap (foliage)	Z	Sand Wind Dust Goggles
AA	D Cell L Shaped Flashlight (red lens)	BB	White Socks (1 pair with no logo)
CC	Belt (tan)	DD	Earplugs (1 pair with case)
EE	Socks (green/tan/black) (3 pair)	FF	Poncho

The following clothing and equipment was worn in addition to the above carried load:

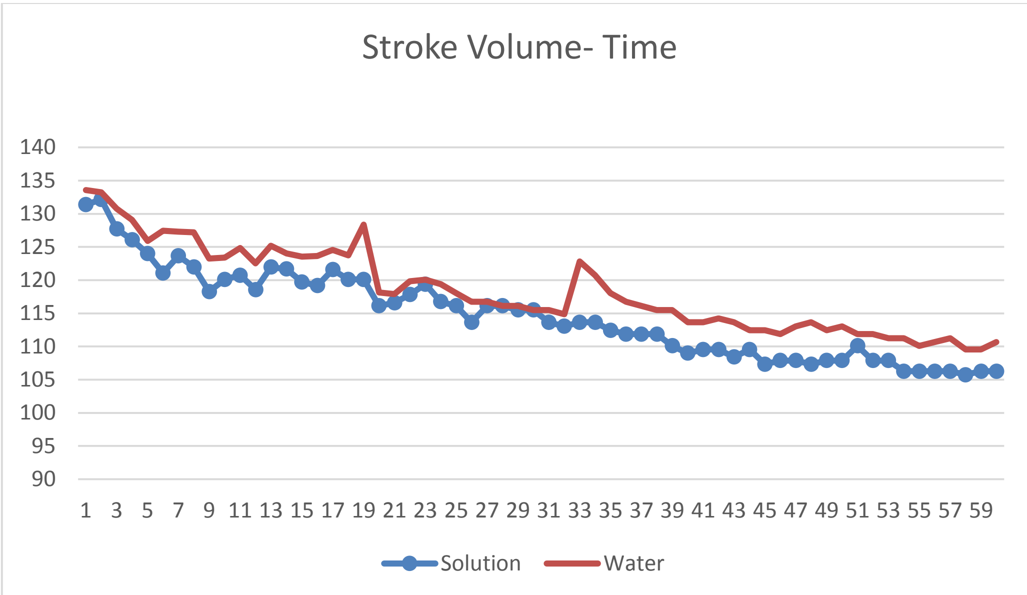
GG ACU Top with the following items (no badges):
- US ARMY Name Tape
- Name Tape
- Rank
- Unit patch (with appropriate tabs)
- US Flag (no IR or subdued flags)

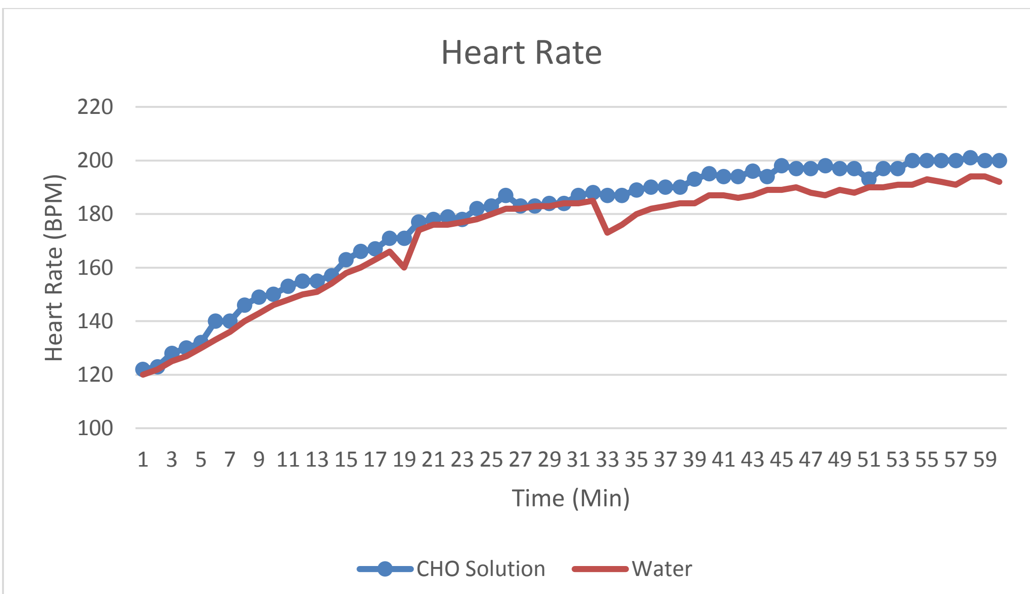
JJ ACU Bottom
KK Belt (tan)
LL Socks (green/tan/black)
MM Hot Weather Desert Boots

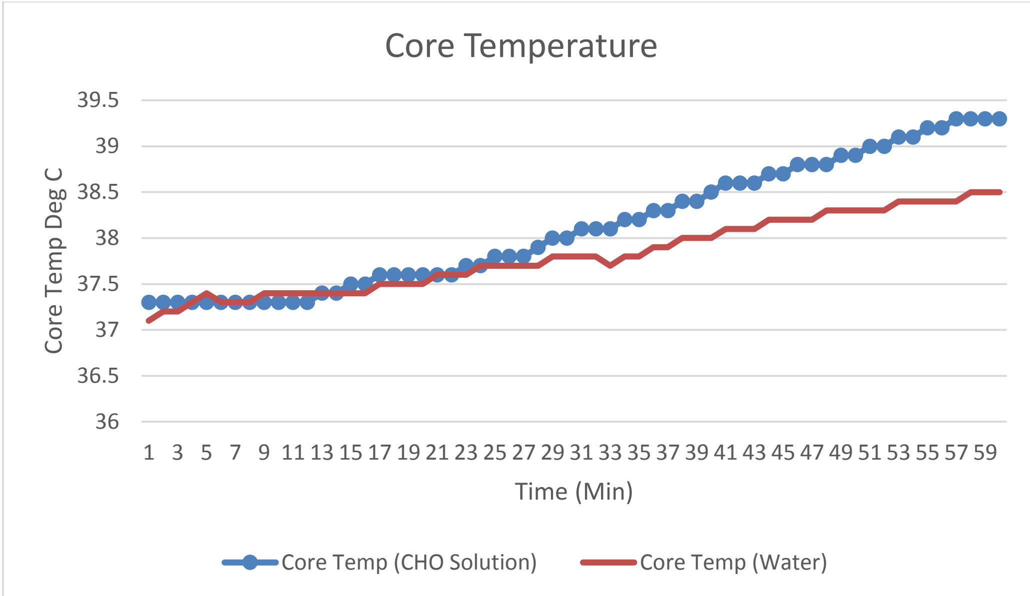
The total equipment load during testing was 18.14 kg (40lbs).

Appendix E

Subject 1

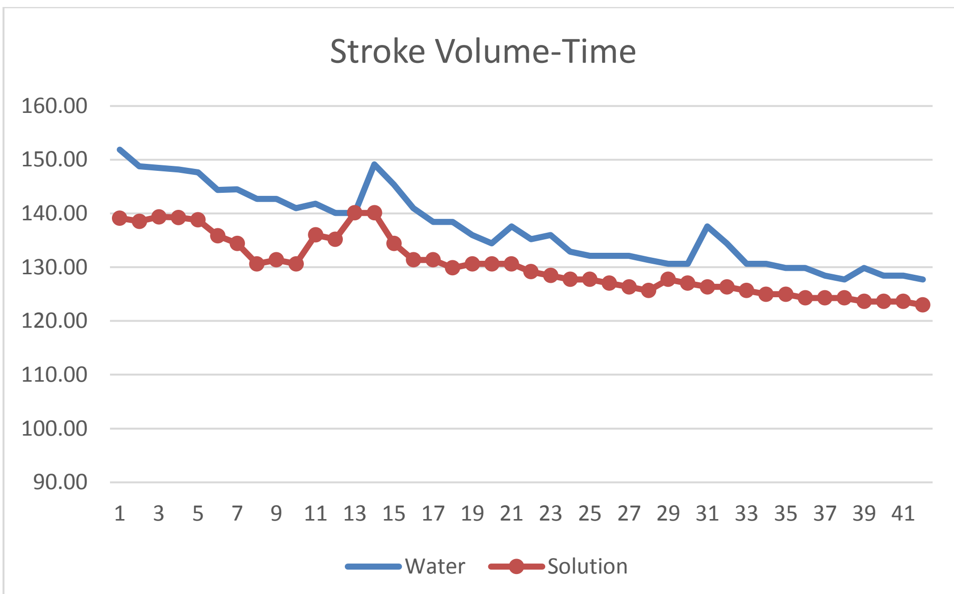




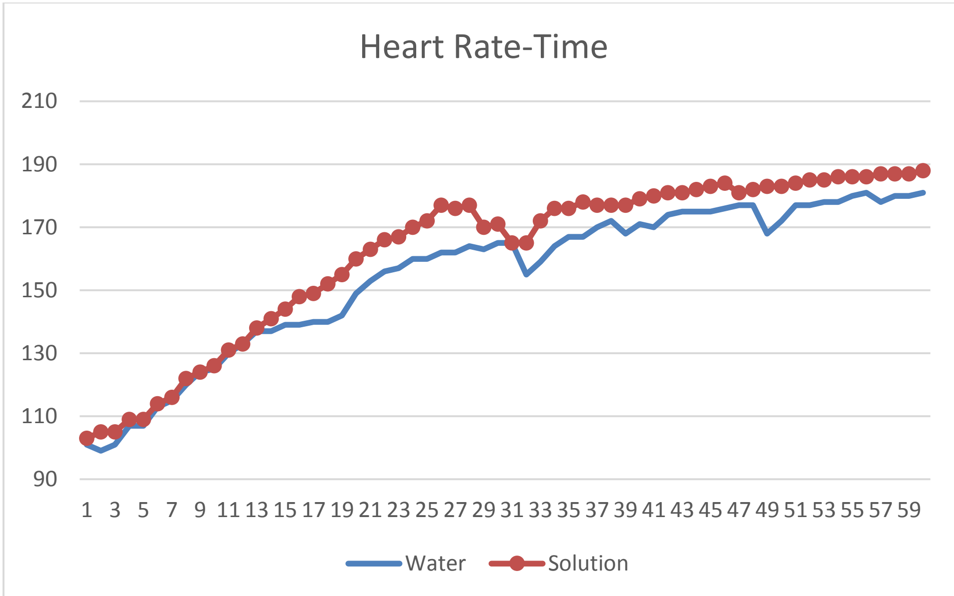


Core Temperature
39.5
39
38.5
38
37.5
37
36.5
36
Core Temp Deg C
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59
Time (Min)
Core Temp (CHO Solution)
Core Temp (Water)

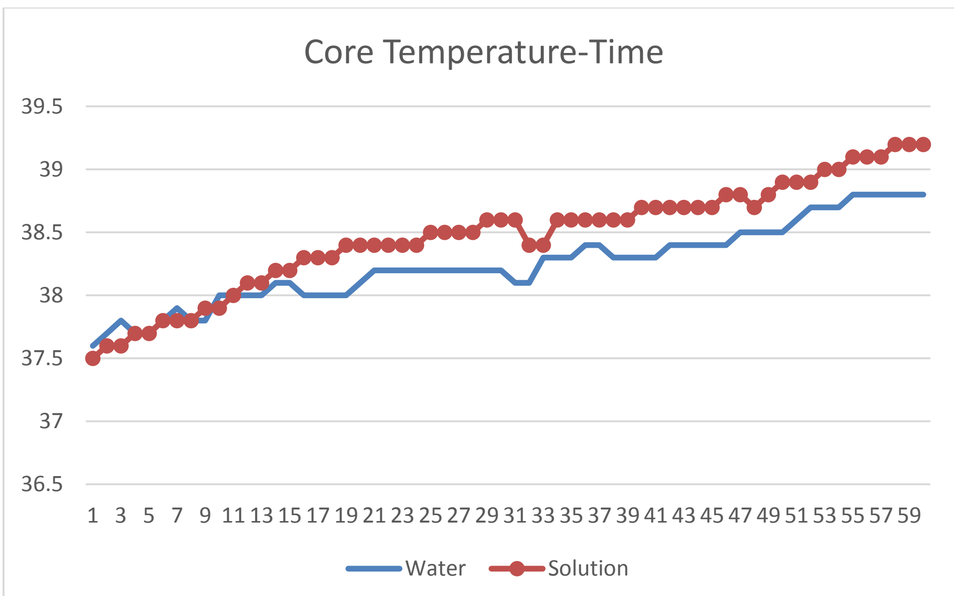
Subject 2



Stroke Volume-Time
160.00
150.00
140.00
130.00
120.00
110.00
100.00
90.00
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41
Water
Solution

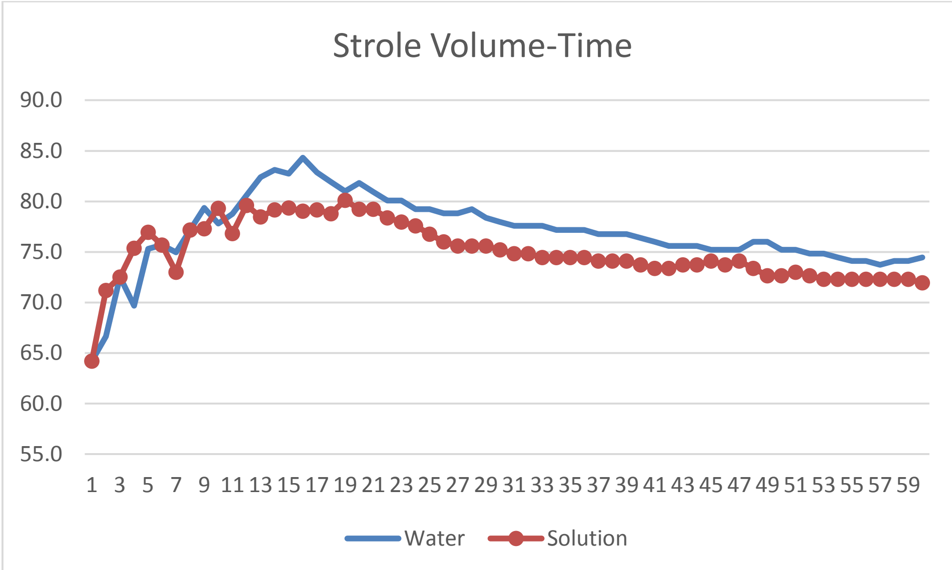


Heart Rate-Time
210
190
170
150
130
110
90
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59
Water
Solution

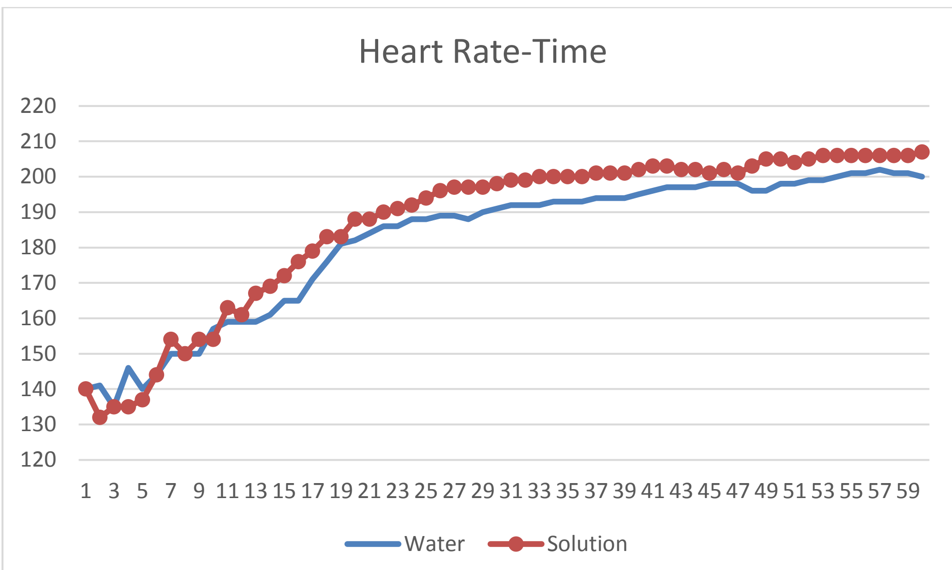


Core Temperature-Time
39.5
39
38.5
38
37.5
37
36.5
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59
Water
Solution

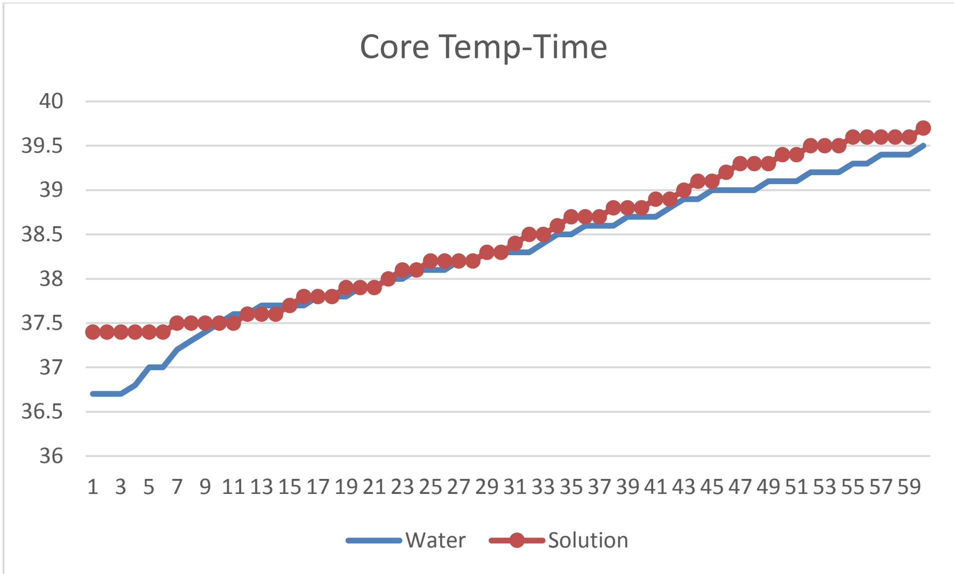
Subject 3



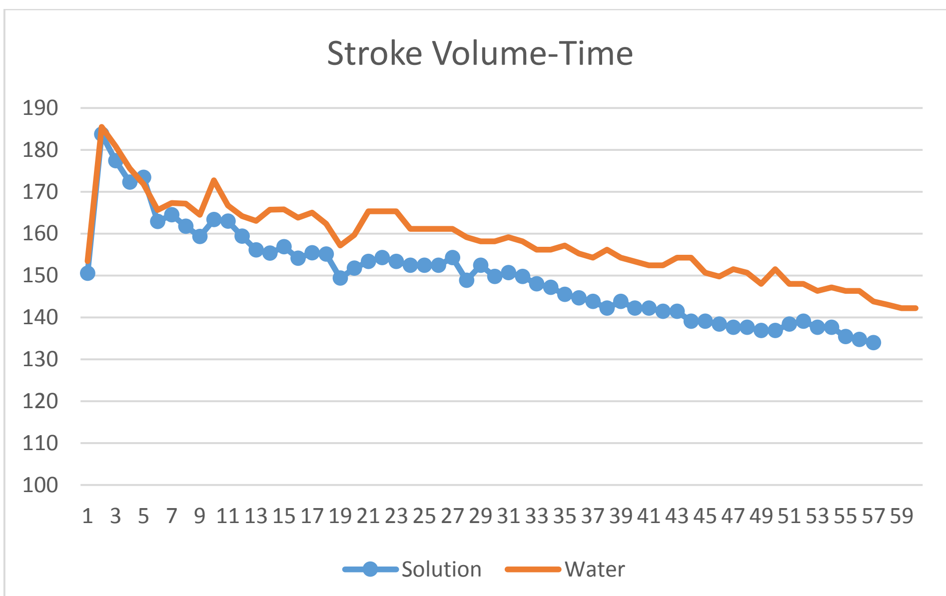
Strole Volume-Time
90.0
85.0
80.0
75.0
70.0
65.0
60.0
55.0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59
Water
Solution

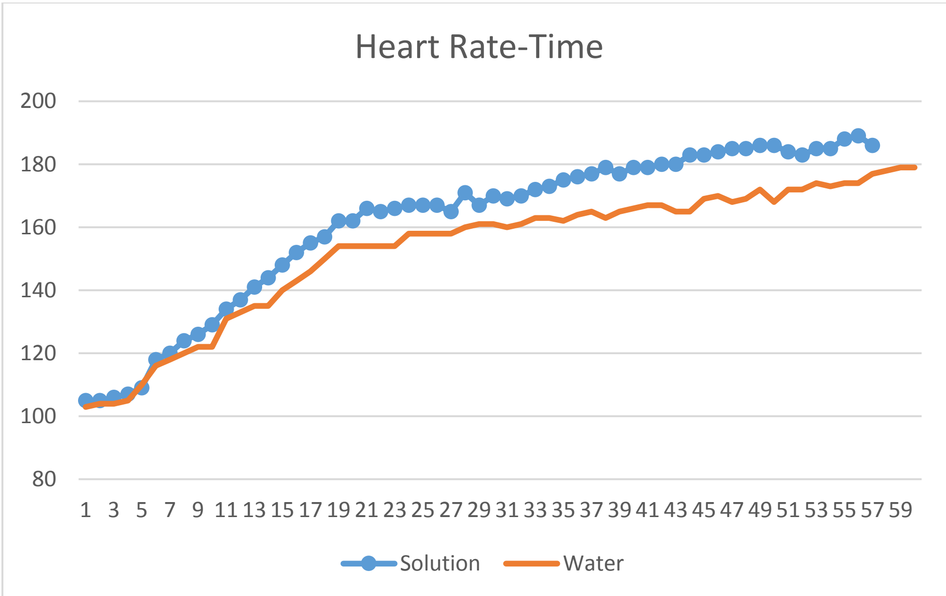


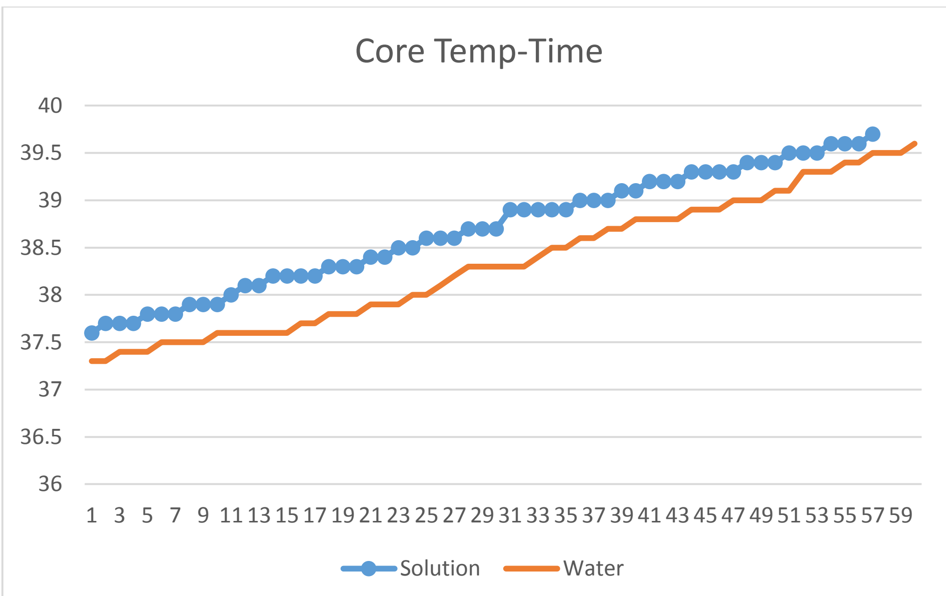
Heart Rate-Time
220
210
200
190
180
170
160
150
140
130
120
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59
Water
Solution


Core Temp-Time
40
39.5
39
38.5
38
37.5
37
36.5
36
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59
Water
Solution

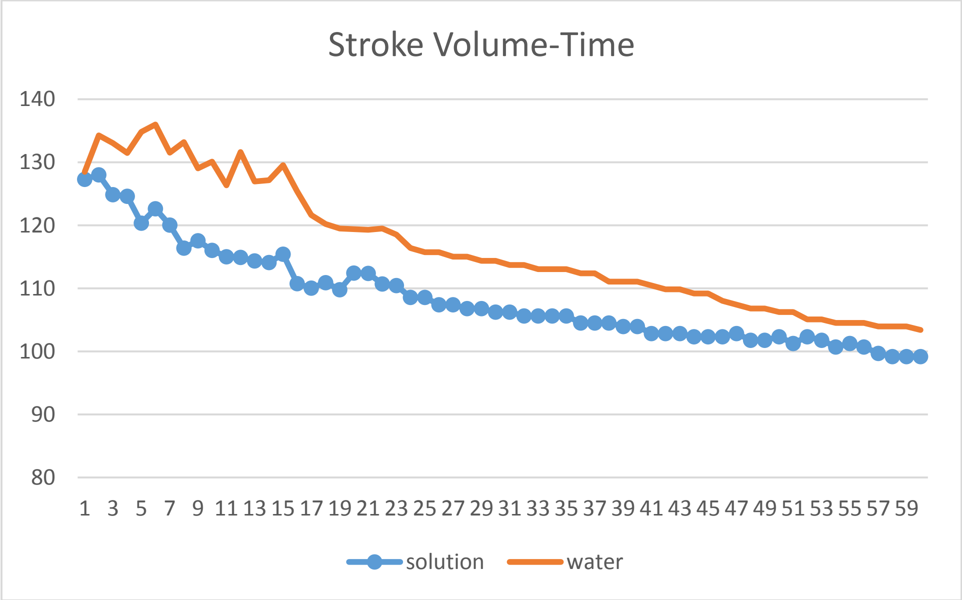
Subject 4


Stroke Volume-Time
190
180
170
160
150
140
130
120
110
100
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59
Solution
Water

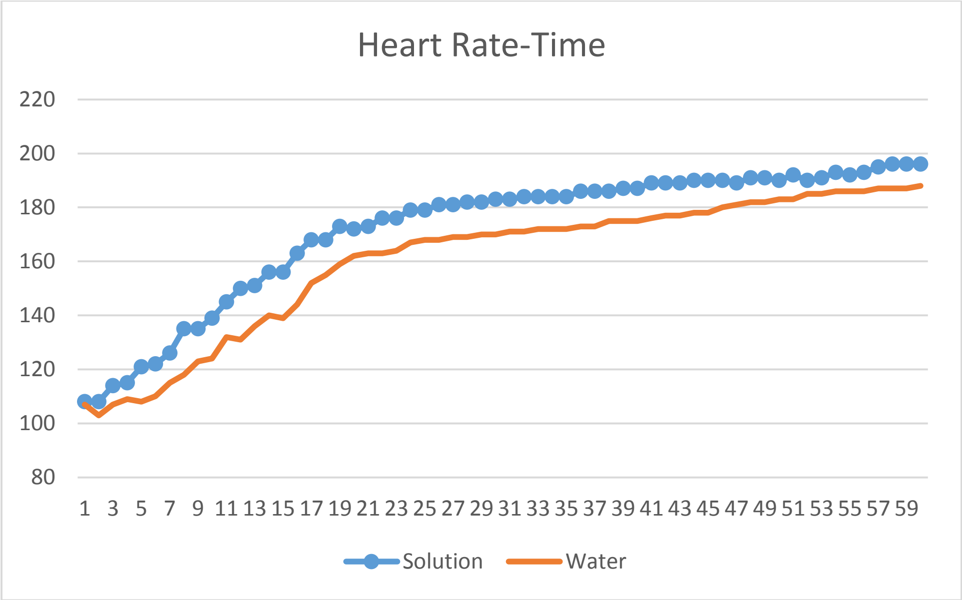

Heart Rate-Time
200
180
160
140
120
100
80
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59
Solution
Water


Core Temp-Time
40
39.5
39
38.5
38
37.5
37
36.5
36
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59
Solution
Water

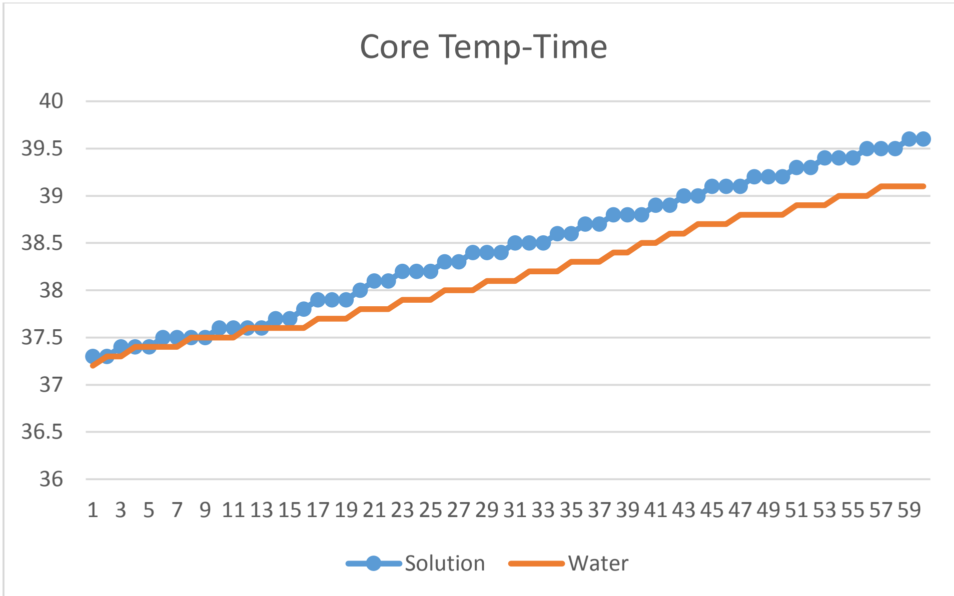
Subject 5



Stroke Volume-Time
140
130
120
110
100
90
80
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59
solution
water



Heart Rate-Time
220
200
180
160
140
120
100
80
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59
Solution
Water



Core Temp-Time
40
39.5
39
38.5
38
37.5
37
36.5
36
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59
Solution
Water