The effect of dehydration and rehydration with a high potassium beverage on muscular strength in collegiate males

by

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ABSTRACT

Introduction: Dehydration has been shown to impact both health and aerobic exercise performance, with less research examining the impact of dehydration on muscular strength. Rapid weight loss via dehydration is a common practice in several weight class sports dealing with muscular strength and power. Exercisers may also unintentionally begin a resistance training session in a dehydrated state as a result of hot environmental conditions or failure to restore fluid balance following previous activity, possibly inhibiting performance. Most rehydration strategies have focused on the inclusion of sodium in a beverage to restore plasma volume, while less have considered the role of potassium. **Purpose:** The purpose of this study was to determine the impact of exercise dehydration and rehydration with a commercially available high potassium sports drink versus a sugar water placebo on strength measures. **Methods:** Ten college-age resistance trained males were recruited for this study. Participants came to the lab on two occasions for different treatment conditions in a randomized crossover design. Treatment order was counterbalanced for participants. At each visit, participants were asked to dehydrate 3% of body mass for up to 120 minutes via low intensity cycling in a heated chamber, (40 deg C [104 deg F], 60% RH) followed by a rehydration protocol. The rehydration protocol consisted of a total fluid volume in an amount equal to body mass lost during dehydration ($1\ L \cdot kg^{-1}$). Half of the rehydration fluid volume consisted of the test beverage, with the subsequent half consisting of plain water. Rehydration fluids were given at thirty minute intervals for two hours for all subjects. Tested beverages were a commercially available high potassium sports drink and sugar water placebo matched for carbohydrate content. Strength measures consisted of dominant knee extensor and flexor peak torque, leg fatigability and one-repetition maximum bench press. Leg peak torque was measured with an isokinetic dynamometer at three different speeds, while fatigability was measured via a 50-repetition maximal effort test. Strength measures were assessed for participants before dehydration, after dehydration, and after rehydration. **Results:** The dehydration protocol resulted in a mean reduction of 2.82 ± 0.1% of body mass, which remained 0.8 ± 0.1% below euhydration levels following each rehydration protocol. A significant decline was observed in bench press performance and knee extensor isokinetic peak torque at 60 $deg{\cdot}sec^{-1}$ and was not fully recovered with rehydration ($p < 0.05$). Average torque during the 50-repetition test also significantly declined following dehydration but was recovered with rehydration ($p < 0.05$). The high potassium sports drink was not significantly different from the sugar water placebo in its ability to restore performance or hydration status. Neither drink resulted in complete rehydration. **Conclusion:** Exercise dehydration reduced maximal bench press performance and dominant leg extensor peak torque at slower isokinetic speeds, which was not recovered after two hours of rehydration with either a high potassium sports drink or a sugar water placebo.

CHAPTER 1. INTRODUCTION

Dehydration poses a risk to both human health and performance. An individual may begin activity in a hypohydrated state in response to heat stress, exercise fluid loss, or a combination, or with inadequate fluid replacement. Athletes in weight class sports may also intentionally dehydrate with some of these techniques in an attempt to achieve a competitive advantage over their opponents by competing in a lower weight class, before rapidly rehydrating prior to competition. This rapid weight loss is prevalent in as many as half of weight-class sports, including 84% of combat sport athletes (wrestling, boxing, and other martial arts) (1). However, acute dehydration-induced weight loss can have costly physiological effects. Extreme weight loss practices contributed to the deaths of three wrestlers in 1997, so caution must be taken when undergoing these techniques. By contrast, the general exercising population may unknowingly begin exercise in a dehydrated state as a result of inadequate fluid intake prior to activity or inadequate fluid balance restoration following prior activity. Because thirst may be an inadequate stimulus to provide complete rehydration, especially in highly vulnerable populations such as elderly with a reduced thirst response, exercisers may fail to consume sufficient fluids throughout and following a bout of endurance or resistance exercise (2). Furthermore, the rise in popularity of practices such as hot yoga among team sport athletes may contribute to compromised health and performance if athletes are not properly replenishing fluids after this acute heat exposure.

As a result of this fluid loss, individuals may experience performance decrements. Prior research has found a performance deficit with 2% dehydration before endurance events due to increased cardiovascular strain (2). When in a state of hypohydration, a reduction in plasma volume from sweat losses causes a decrease in stroke volume. Heart rate rises in an attempt to maintain cardiac output, eventually resulting in reduced exercise performance. However, less research has considered the effect of dehydration on strength. Variable methods, including exercise in the heat or passive sauna exposure to dehydrate have led to mixed results in the degree of performance decrements and the ability to recover following rehydration. However, it may be that the decrements in muscular strength observed in some studies depends on whether the water loss and recovery of body fluids occurs in primarily the intracellular or extracellular fluid compartment. There is evidence to suggest beverages of different electrolyte compositions may favor the restoration of one of these fluid compartments over the other; higher sodium beverages favor restoration of the extracellular fluid stores, whereas higher potassium may favor restoration of the intracellular fluid space (3). While high potassium beverages such as coconut water have been studied minimally for their impact on endurance performance (4), no study to date has assessed high potassium drinks consumed during rehydration on their ability to restore muscular strength.

The long term goal of this line of research is to determine appropriate hydration strategies to support optimal muscular function during resistance training as well as strength and weight-class sports. The purpose of this study was to examine the impact of 3% dehydration and subsequent rapid rehydration on muscular strength in resistance trained males. This research also sought to determine the efficacy of a high potassium beverage in restoring fluid balance and restoring muscular strength. We hypothesized a state of 3% hypohydration would significantly impair muscular strength in resistance trained males. We also predicted the higher potassium beverage would better restore muscle function and would be associated with improved fluid retention compared to a flavored sugar water placebo.

Significance

Findings from this study will provide additional insight into performance decrements with dehydration as well as potential strategies to restore this decline in exercising populations. This study will also encourage further research in other populations at risk for dehydration, such as older adults, who have a decreased thirst response that may lead them to unknowingly exercise in a hypohydrated state (5). First responders and military personnel will also benefit, since their occupations often require quick bursts of strength and power in potentially dehydrating conditions.

Results of this study will also benefit athletes who undergo drastic dehydration strategies in order to compete in a lower weight class for competition, so that they may restore both appropriate fluid balance and performance. If athletes choose to undergo this risky practice it is important they restore their fluid balance properly after weigh-ins to avoid adverse effects on health (6). Results of this study may also influence athlete decisions to complete drastic dehydration weight cutting protocols if it is shown not to confer any inherent performance advantage.

Innovation

To the author's knowledge, no prior study has assessed the efficacy of rehydration with a high potassium sports drink on the restoration of muscular strength. While high sodium beverages are known to enhance plasma volume restoration and thus a reduction in cardiovascular strain, the precise mechanism underlying reductions in muscular strength with dehydration remain unknown. Revisiting potassium and its potential role in intracellular fluid restoration could generate more questions as to whether or not hydration at the muscle level may be a mechanism of strength decline with dehydration.

CHAPTER 2. REVIEW OF LITERATURE

Hydration and Health

Water is essential for human life, and deficiencies in body water can lead to a host of physiological consequences (7). Among these, some evidence has linked dehydration with impaired cognitive function (8), glycemic control (9), and kidney function. Thus, it is critical that one adequately replenish fluids following losses incurred by exercise, heat stress, or a combination, or simply the result of chronic inadequate fluid intake.

Hydration and Performance

Intentional dehydration is common among athletes from weight class sports attempting to qualify to compete in a lower weight class for competition. Sports with specific weight categories for competition include horse racing, weightlifting/powerlifting, and combat sports (e.g. wrestling). Use of strategies aimed at reducing body water levels is prevalent in as many as 84% of combat sport athletes (1). Athletes in these sports will often attempt to reduce their body weight in the short-term to compete at a lower weight class, followed by a rehydration period in which some, but often not all, body mass is restored. However, this rehydration may be incomplete, and the effects of the acute fluid loss on parameters of muscle strength still warrants further investigation based on the variable methods used among studies. Extreme weight loss has even been associated with the deaths of some athletes, including three wrestlers in the nineties (6, 10).

It has been well established that dehydration negatively impacts endurance performance (11). Although athletes in these sports would not intentionally dehydrate prior to a competition, considerable evidence suggests incomplete fluid restoration following exercise fluid loss can cause performance decrements in a subsequent session initiated in a state of hypohydration (12). This is thought to mainly result from the detrimental impact of fluid loss on the body's thermoregulatory processes (13). In order to maintain cardiac output, exercisers with this fluid deficit will experience an elevated heart rate to compensate for the reduction in stroke volume resulting from increased plasma volume losses incurred by sweating. However, significantly less research has been conducted regarding the effect of this dehydration on muscle strength and power.

A recent meta-analysis by Savoie and others found dehydration of ~3% to impair muscular strength by approximately 5.5%, with no significant differences between the decrements in upper and lower body strength (14). The studies examined in this review varied in their dehydration techniques, including exercise in the heat or passive sauna exposure (15, 16).to achieve the desired fluid deficit. These variations in the dehydration protocols used for various studies make conclusions difficult to draw. This further raises the question of whether muscle fatigue in itself from the dehydration protocol impairs measures of muscular strength. However, it seems heat exposure primarily impairs muscular endurance-based activities, while any effects on muscular strength are less clear (17). Despite the methodological limitations in many of these studies, the current literature general supports reductions in anaerobic performance with body water deficits of at least 3% (2).

Our lab previously examined the influence of a state of 5% hypohydration on peak torque and muscle metabolism during exercise in competitive wrestlers (18). In this study peak torque of the upper and lower body decreased in wrestlers. Five hours of self-selected rehydration was not sufficient to overcome this performance deficit. Since then, updated mandates have placed weigh-ins for wrestling competitions and other sports to two hours prior competition in an attempt to reduce drastic weight-cutting practices.

Another study in wrestlers found an incomplete restoration of muscle strength following rehydration with water, though the dehydration protocols used were uncontrolled and also included caloric restriction (19). Another study by Pallares et al. tested combat sport athletes and found recovery of bench press performance with complete rehydration (1). However, based on its close proximity to a national level competition, it is questionable whether athletes in this study put forth their best effort in either of the strength tests knowing they were to compete in a few hours. Athletes were also left to rehydrate in whatever manner they desired, so it is unknown what additional dietary or supplemental factors may have influenced this body mass restoration. Regardless, this study had high external validity as it tested athletes cutting weight as they would prior to an actual competitive event, though findings may not be as applicable to the general effects of dehydration on performance.

Two studies have assessed dehydration related to complete bouts of resistance training. One study by Kraft et al. found an impairment in performance during a full body resistance exercise session following 3% dehydration which resulted in fewer repetitions completed per exercise, higher RPE, and higher heart rate throughout the activity (20). Another study by Judelson et al. observed decrements in repeated resistance exercise performance both at ~2.5% and ~5% body water deficits (21). Thus it is important to maintain adequate hydration status throughout resistance training, not only for the preservation of maximal strength, but also in order to successfully complete the desired resistance training volume during an exercise bout.

In contrast, some studies have observed no decline in strength performance (15, 22) during isometric contractions. Thus, it seems further investigation is warranted to confirm the effects of states of hypohydration on muscular strength performance.

While much research has been done concerning the effect of rehydration on endurance exercise performance, little research has been done regarding rehydration prior to strength and power activities. Schoffstall and colleagues observed a 5.6% decline in the bench press performance of competitive powerlifters following 1.5% passive dehydration, though ad-libitum water consumption in a 2-hour rest period overcame this strength deficit (16). However, it is unclear whether water alone would be sufficient to restore muscular strength during the bench press with more severe dehydration such as 3% or if alternative methods of rehydration would be more beneficial.

Interestingly, one study compared rehydration with deep-ocean mineral water to spring water or a carbohydrate electrolyte sports drink and found a faster return to baseline hydration status and lower body muscle strength (23). The drinks in this study were all supplied in an amount equal to body mass lost from 3% heat and cycling dehydration. Although each group did not completely recover isokinetic lower body peak torque performance, the group receiving Kona mineral water had a more significant increase towards baseline, which the authors suggest may be related to the mineral content in this water, including sodium, calcium, potassium and magnesium in the drink influencing neuromuscular function. Because ~3% dehydration seems to be the point at which most studies suggest strength loss occurs, it is warranted to continue to test dehydration and rehydration at this level of dehydration.

Possible Mechanisms of Reductions in Muscular Strength and Power

While the thermoregulatory strain incurred by dehydration seems the primary factor contributing to declines in endurance performance, the precise mechanisms behind which muscular strength deficits occur in some studies remains subject to speculation. Some have suggested potential decrements to neuromuscular activation as a contributing factor to declines in strength with dehydration. The majority of studies on this topic have not found any significant change in EMG activation data for muscles during strength isometric, isokinetic or repeated fatiguing tasks despite observed declines in performance (14, 24, 25). Even when isolated from any effects of heat stress, a common cofounding variable in dehydration studies, moderate dehydration does not seem to reduce voluntary activation of muscle fibers during moderate dehydration (22). One study by Bowtell et al. found hypohydration increased peripheral muscle excitability when dehydrated, yet this was not enough to overcome performance declines during eccentric and isometric exercise (24). In this study peripheral and cortical voluntary activation were the same between euhydrated and dehydrated conditions, though participants experienced increases in inhibitory inputs while euhydrated compared to dehydrated. Further research is required to properly determine mechanisms by which these declines in strength occur and to deepen our understanding of nervous system changes that may be occurring with dehydration.

Hydration Assessment

There are various methods in assessing one's hydration status, each with their own strengths and weaknesses (26, 27). Among these measurements, changes in body mass provide the most practical measurement of acute water loss. An exerciser may weigh themselves before and after an activity under the same conditions (typically nude as to account for any sweat trapped in clothing) and can predict the percent change in body mass is due to water loss. Metabolic water losses are another contributing factor to mass lost throughout exercise, though during low intensity exercise most studies assume this amount to be negligible. However, some studies have chosen to correct for the amount of body mass lost when the oxygen consumption is known during the dehydration protocol.

Additional indices of hydration status include urinary markers. While urinary specific gravity may provide a valid indication of acute hydration status, it may not be a reliable means of measuring acute changes in hydration status following activity and with rapid rehydration (26).

Blood and urine osmolality are other methods of assessing hydration status, though require more costly equipment which would typically only be available in a laboratory environment. Similarly, plasma volume change may be used to estimate extracellular water loss. Changes in concentrations of hematocrit or both hemoglobin and hematocrit can be used to estimate percent change in plasma volume from baseline, as more concentrated values correspond with a decrease in plasma volume (28).

In evaluating effects of dehydration, one should also consider the source of the fluid loss, as this may have differential effects on the body. In general, total human body water may be divided based on its transient location into intracellular and extracellular fluid stores. During exercise dehydration, body fluids seem to be lost from both cellular compartments. While in a relative sense these fluids come more from the extracellular space, absolute water losses from exercise dehydration at levels of dehydration between 2.2% and 5.8% seem to be similar between intra- and extracellular spaces (29) when measurements are taken from the exercised muscle thirty minutes following dehydration. In particular, following 4.1% and 5.8% dehydration, Costill and others also observed greater relative water losses in the extracellular fluid space. In the absence of any rehydration beverage consumption, Nose and others found plasma volume losses of 9.4% induced by exercise and heat induced dehydration to recover to only a 5% decrement after thirty minutes of recovery (30). Fluid shifts from the intracellular and interstitial fluid spaces may account for this plasma volume recovery in the absence of any endogenous fluid source. Thus it seems the body prioritizes the recovery of plasma volume when there is a pronounced fluid decrement, as Nose and others found that while plasma volume recovered, water from the interstitial and intracellular spaces did not recover. This rapid recovery of plasma volume seems to be more pronounced following heat acclimation, with a greater proportion of this plasma volume restoration coming from the intracellular fluid space (31). By prioritizing restoration of this fluid space, one can subsequently maintain cardiac output, reducing cardiovascular strain. This seems reasonable, considering preservation of cardiac function would be more immediately essential to survival than function of peripheral tissue such as skeletal muscle.

Rehydration Strategies

Current fluid recommendations from the American College of Sports Medicine advise fluid consumption equal to ~1.5 L per kg of fluid lost during the activity in order to achieve rapid and complete recovery from dehydration (5). This volume beyond what was lost during dehydration is meant to compensate for increased urinary water losses in response to rapid consumption of large volumes of fluid. However, the addition of carbohydrates and electrolytes to rehydration beverages may facilitate rehydration and reduce associated urinary fluid losses. It seems restoring fluid through ingestion of at least the amount lost during dehydration is required to restore fluid balance (2).

Several different factors may influence the ability of a particular fluid to restore total body water, as well as the distribution of fluid throughout the body.

Carbohydrate Content

Beverage composition also influences both the rate of gastric emptying from the stomach as well as the rate of water absorption through the small intestine. Typically, more concentrated and thus caloric and/or carbohydrate dense beverages slow the rate of gastric emptying. However, generally solutions up to about 10% carbohydrate seem to empty from the stomach at a rate similar to water (32). When beverages of higher concentration are consumed, there is a secretion of water into the intestine from the extracellular fluid, which may exacerbate dehydration (33). The inclusion of carbohydrates seems primarily useful for the replenishment of energy stores such as muscle glycogen, which would be of benefit for recovery from exercise and subsequent performance bouts (34, 35). One study compared the effect of different carbohydrate contents in an electrolyte beverage on fluid retention (36), finding a 12% carbohydrate-electrolyte solution retained more fluid than a 3%, 6%, electrolyte-only or placebo beverage during 4 hours of recovery from exercise dehydration. While the higher carbohydrate content in this study did promote more fluid retention, this may have been the result of a delay in gastric emptying, which would not be ideal for rapid rehydration strategies.

Temperature

Beverage temperature may also play a role in gastric emptying and fluid retention. It seems cold (refrigerated) beverages tend to increase water retention of the ingested fluid (37). It may be of benefit to exercisers to consume cooler beverage in order to promote the return of fluid balance during the rehydration period.

Electrolytes

The extracellular and intracellular fluid compartments contain different levels of electrolytes, notably sodium and potassium. Sodium, found in higher concentrations in the extracellular fluid, is known to be important for consumption in restoring extracellular fluid volume after dehydration (38, 39). Potassium, however, may be more important in restoration of intracellular water, as it is the primary electrolyte of this fluid space (40, 41).

One study by Nielsen et al. compared water, a high sugar beverage, and a high sodium beverage in their ability to rehydrate and improve endurance performance (42). Men underwent 3% dehydration through exercise in the heat before consuming each beverage on different days, with results suggesting a higher potassium beverage may better restore intracellular fluid volume, whereas a higher sodium beverage may have a greater impact on extracellular (plasma) fluid volume(42). Despite rehydration, performance decrements were still observed in the endurance tests used in this study, though some of this performance decline may be attributed to a loss of muscle glycogen induced by the exercise dehydration protocol. As muscular strength seems unlikely to be reduced from glycogen reduction provided there is sufficient recovery time between maximal effort attempts (43, 44), it would be interesting to see if this decline was still present in rehydration prior to strength assessments. Similarly, Maughan and others found the inclusion of potassium chloride in a beverage to be as effective in retaining water after exercise-induced dehydration as a high sodium, glucose, or mixed beverage (3). Investigators in this study also observed a delay in the restoration of plasma volume one hour after rehydration when the potassium beverage was consumed compared to a beverage with sodium, glucose, or a combination of glucose and all three electrolytes. However, plasma volume was recovered by two hours following rehydration. Since Rehrer and others found no significant effect of potassium added to a carbohydrate beverage the on rate of gastric empting (45), it may be that the results from Maughan's group may be explained by a preferential restoration of the intracellular fluid space when participants consumed a high potassium beverage rather than any residual volume remaining in the stomach. Unlike in Nielsen's study, no calculation was made for intracellular water in Maughan's study.

Another more recent study compared the ability of a branched chain amino acid electrolyte beverage to rehydrate compared to an electrolyte carbohydrate beverage and flavored water. This study found similar total body rehydration between beverages, though the amino acid electrolyte beverage seemed to better increase estimated intracellular body water (46). In this study the amino acid containing beverage also contained a significantly greater potassium concentration, further supporting the notion that potassium intake may be more important for restoring the intracellular fluid space.

One newer beverage on the market, BodyArmor, is promoted for its high potassium content and low sodium content compared to competitor hydration beverages. The potassium concentration of 37.9 $mmol \cdot L^{-1}$ of this beverage comes closer to the 51 $mmol \cdot L^{-1}$ concentration of potassium used by Nielsen et al. than conventional carbohydrate-electrolyte sports drinks. Although sodium has often been touted as the important electrolyte for restoration of plasma volume, it would be interesting to see how a commercially available high-potassium, low-sodium beverage compares in its ability to rehydrate intracellular water stores and potentially restore performance.

Prior studies have examined the utility of a high-potassium beverage, coconut water, for its effect on fluid balance, though few have looked at exercise performance. One study by Kalman et al. compared the effectiveness of bottled water, coconut water, coconut water from concentrate, and a carbohydrate electrolyte sports drink for their effect on treadmill time to exhaustion. Coconut water promoted similar changes in hydration to the sports drink as measured by body mass, fluid retention, plasma osmolality, and urinary specific gravity (4). However, participants in this study also reported greater feelings of bloating and stomach upset. The beverage used in our study, BodyArmor, also incorporates coconut water into its formulation, though it may have greater palatability than the coconut water used in prior studies due to the incorporation of additional non-nutritive flavorings to create a taste similar to traditional sports drinks. Thus this drink may be more application to real-world exercise rehydration scenarios as something an exerciser would choose to consume.

There are still some inconsistencies in the literature regarding the hydration capacity of potassium rich beverages. Another study compared the rehydration index of sodium enriched coconut water, coconut water, a sports drink, and plain water (47). The sodium enriched coconut water increased fluid retention as expected based on sodium's known role in plasma volume restoration, though the potassium response differed from previous studies. Notably, there was a similar rise in plasma volume during rehydration, unlike the delay in plasma volume restoration observed in other studies incorporating potassium rich rehydration beverages. Another study examined the ability of another naturally potassium rich beverage, fluid milk (45 $mmol \cdot L^{-1}$), in its ability to rehydrate (48). Participants in this study consumed water, a carbohydrate-electrolyte beverage, milk, or milk with added sodium chloride. Both milk and milk with added sodium consumed during sixty minutes of rehydration resulted in more positive fluid balance than the water or carbohydrate-electrolyte drink, although the additional sodium did not further enhance fluid balance. Several factors may have contributed to this result, including potential delays in gastric emptying due to the additional energy from protein and fat in the milk, although since this effect was present several hours into rehydration, the authors attribute this effect more to the natural electrolyte content of milk. Therefore, it seems further research is required concerning the potential role of potassium during rehydration.

Electrolytes and Exercise

With muscle contraction, there is an efflux of potassium from the cell as the cell repolarizes. It may be that the decline in intracellular water calculated in Nielsen's study may be partially attributed to potassium leaving the cell. Perhaps rehydration with a high potassium beverage may accelerate the rehydration of the intracellular space with the increase in the K^+ transport back across the cell membrane. Although during and after high intensity exercise there is a pronounced elevation in plasma K^+ levels, followed by a rapid decline (hypokalemia), this is not observed at lower intensities (49). Prolonged, submaximal exercise has been associated with a net loss of potassium from skeletal muscle, leading to a lower resting membrane potential. Water flux is thought to account for up to 50% of the rise in plasma $[K^+]$, which should theoretically be more pronounced with exercise dehydration. Perhaps these changes in water distribution and potentially membrane potential may impact the ability of the cells to elicit a maximal contraction. However, this effect is unclear, as in the absence of pronounced dehydration, Na^+/K^+ pump activity seems to return to baseline levels within four minutes following exercise, thereby restoring membrane potential (49). Maughan (3) observed a decline in plasma potassium levels following exercise dehydration and rehydration with different electrolyte beverages, though there was no difference between drinks. By contrast, the study by Nielsen (42) found a significant rise in plasma potassium concentrations following rehydration when subjects consumed either the high-potassium or high-sugar drink. In this same study, muscle potassium levels tended to decrease slightly during exercise dehydration and increase back towards baseline during rehydration, and these values were not significantly different between drinks. Therefore, it seems the electrolyte concentrations within the body are well regulated on this time scale, though perhaps a high-potassium beverage may hasten this recovery process of both fluid and electrolyte balance through a more pronounced concentration gradient.

Dehydration has been found to reduce the ratio of testosterone to cortisol in the body during exercise dehydration (50). Following exercise the body may be in a more catabolic state from these fluid losses. Further research is required to determine the impact of this state of hypohydration on these hormonal changes in the body and the role rehydration may play in recovery.

Some evidence also suggests cellular dehydration may have a detrimental effect on protein synthesis (51). It follows that maintenance and restoration of muscle cell hydration, possibly through the provision of a high potassium beverage, may help reduce this effect. Resistance exercisers may therefore wish to prioritize recover of cellular water stores to further support muscular adaptations. However, further study is required to determine the impact of chronic dehydration on the adaptations to resistance exercise.

Continued uncertainty about the precise means by which muscular strength may be reduced following dehydration, as well as the less explored role of potassium during rehydration led to the implementation of the present study. The purpose of this study is to further explore the effect of dehydration on muscular strength and potential rehydration strategies to recover from strength losses.

CHAPTER 3. METHODS

Subjects

Preliminary power analysis suggested 10 subjects were required to find any significant interaction between time and the assigned rehydration beverage on hydration and performance measures. Subjects were collegiate (18-35 y old) males who met the following criteria: reported an estimated 1-RM bench press of at least 1.25 x morning body mass, had at least 3 years of self-reported resistance training experience, and were currently engaged in a resistance training program at least 3 days per week. Males were chosen to eliminate the potential for any variable fluid balance shifts associated with female menstrual cycle, since subjects were tested on multiple occasions (52). Subjects were excluded if they were currently supplementing with creatine or currently taking any prescription medications thought to interfere with hydration levels (e.g. diuretics) (53). Subjects were also excluded if they had any pre-existing medical condition that would put their health at risk during the dehydration and/or strength tests. These details were determined with a medical health history questionnaire. Because all subjects were resistance trained, they were familiar with the equipment utilized for the sports-specific measures of muscular strength employed in this study.

This study was approved by the Institutional Review Board at Iowa State University (APPENDIX C), and all subjects provided signed informed consent prior engaging in any testing procedures.

Table 1 *Subject characteristics*

Age, y	23 ± 1
Body Mass, kg	86.4 ± 2.0
Height, cm	178 ± 2.2
BMI	27.4 ± 0.9
% body fat, 3-site skinfolds	11.7 ± 1.7
Baseline Strength (Estimated 1-RM:body mass)	1.39 ± 0.04

Values are presented as means ± SE, n = 10

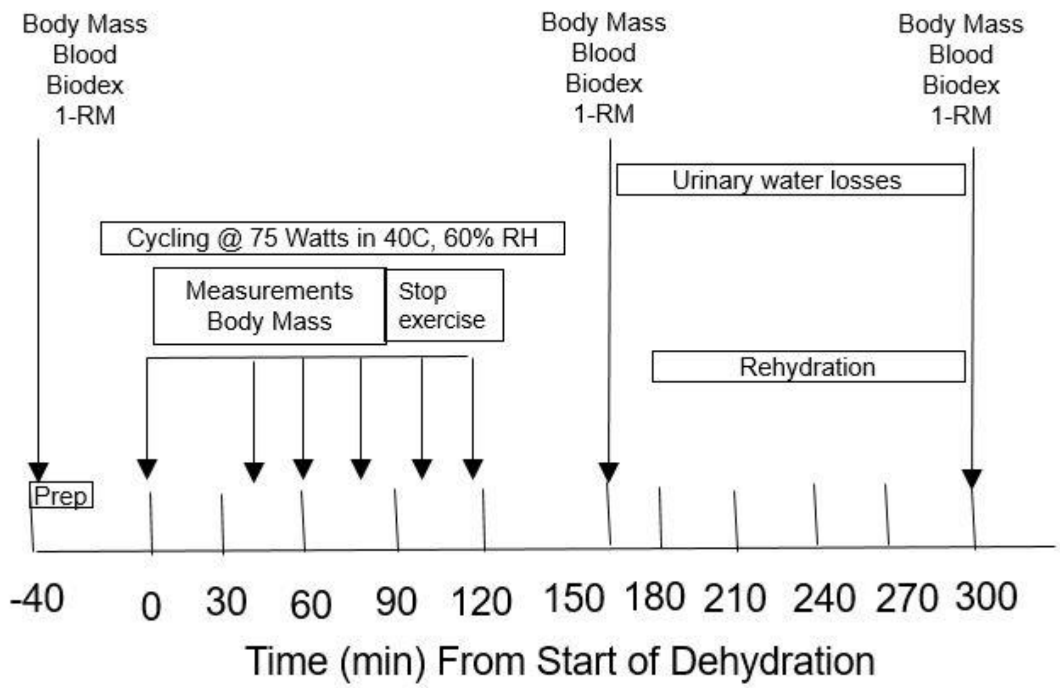

Figure 1 Timeline of each experimental trial.

Procedures

Participants were asked to maintain their typical diet and training routine throughout the study, though they were not permitted to exercise at least 48 h prior to each visit. Participants also completed a three day diet record for the three days preceding the first experimental trial, which they were asked to replicate leading up to their subsequent trial. Caffeine intake was not permitted the morning of any of the lab visits, and participants were instructed not to consume alcohol for two days prior to each experimental trial in an attempt to ensure euhydration (54). Participants were also asked to consume at least an additional liter of water the day before each experimental trial.

At their initial visit, participants completed a euhydrated (EUH) familiarization trial. For this visit, participants were not required to observe the above restrictions on caffeine intake, exercise, etc. This day was used to determine participation eligibility via the medical history questionnaire and to familiarize subjects with the strength testing equipment. Upon arrival at the lab, participant height was measured via stadiometer and body mass via a standard scale. Participant baseline body fat percentage was also measured by a trained professional using the 3-site Jackson-Pollock skinfold formula (55). Participants then completed one testing battery consisting of isokinetic strength and fatigue measures, as well as one-repetition maximum bench press testing.

In this testing battery, participants completed an isokinetic strength test of the dominant limb on an isokinetic dynamometer (Biodex, Shirley, NY). Participants were instructed to extend their dominant leg as forcefully as possible and flex their leg as forcefully as possible at a set isokinetic speed. Participants completed three sets of three repetitions of knee flexion and extension at different speeds, consistent with previous performed in our lab, similar to a protocol used by Hayes and Morse (58). Participants completed one set at each speed of three repetitions at 60, 120, and 240 $deg \cdot s^{-1}$ and were measured for peak torque of each set for both extension and flexion. Two minutes of rest separated each set.

Participants also completed a 50-contraction fatigue test to determine muscular endurance. This fatigue test consisted of 50 knee extensions based on previous work in our lab (59). Participants completed the knee extensions at a speed of 120 $deg \cdot s^{-1}$with measurements taken for peak torque of each contraction. Peak torque of each rep was averaged.

To determine the effect of dehydration and rehydration on a more sport-specific performance measure, participants were then tested for one-repetition maximum (1-RM) bench press performance using standard barbells and weight plates and following a modified ACSM max testing protocol (60). Participants completed a standardized warmup of dynamic upper body stretches before progressively increasing the weight on the bar until a true 1-RM was observed. As a measure of perceived effort, after each 1-RM attempt for the bench press, participants verbally provided a RIR-RPE rating (61). This scale has previously been used in strength sports, particularly powerlifting, and has been established as a practical method to provide feedback during a 1-RM test.

At least a week later, participants returned for one of two experimental trials. At the start of each visit, nude body mass was measured. An 8 mL blood sample was taken by venipuncture before completing the strength testing battery. A tourniquet was used during the blood collection. Following these initial strength measures, participants completed an exercise dehydration protocol in an environmental chamber (40 deg C, 60% relative humidity), using a Lode Excalibur cycle ergometer (Lode, the Netherlands) at a low intensity

(75 w). Participants were asked to cycle in this chamber and were toweled off and weighed 40 minutes into dehydration, as well as every 20 minutes thereafter, until either ~3% body mass loss was observed or when the total time in the heat chamber exceeded two hours. Participant oral temperature was measured during each weighing period, and if any participant temperature exceeded 38.9 deg C (102 deg F) they were asked to stop the dehydration protocol. Heart rate was monitored throughout the exercise dehydration with a Polar heart monitor (Polar), and participants were instructed to cease cycling if their heart rate exceeded 180 $bts{\cdot}min^{-1}$. Another blood sample was taken at the conclusion of the dehydration protocol, and participants repeated the same strength testing battery before beginning rehydration.

Participants then underwent two hours of rehydration in order to simulate the time allotted for powerlifting and some other weight class competitions between a “weigh-in” and a competition. In a randomized, crossover, double-blind design, each participant was randomly assigned a rehydration beverage following dehydration. Participants randomly received flavored sugar water (orange Koolaid, Kraft Foods, Northfield, IL), or BodyArmor (37.8 $mmol{\cdot}L^{-1}$ K^{+}) (BA Sports Nutrition, Beverly Hills, CA). Participants were not told what beverages they were consuming or given any information to indicate one may have been of greater benefit than another. Beverage consumption was divided into four boluses, with total fluid volume equal to $1L{\cdot}kg^{-1}$ fluid lost during dehydration similar to previous work in our lab dealing with rehydrating electrolyte beverages (56). These boluses were consumed at time points 0, 30, 60, and 90 minutes from the start of rehydration. The first two boluses consisted of one of the two test beverages, while the second two boluses consisted of plain water. Any urine producing during this time was collected and weighed. Rehydration was then assessed with body mass measures and another blood sample following rehydration.

All beverages were consumed at temperatures similar to their actual consumption temperature, similar to previous work in our lab (56). The experimental beverages were kept refrigerated at 4 deg C, while the water was kept at a room temperature of approximately 22 deg C. Following rehydration (RHY), participants were reassessed on the measures of isokinetic strength, fatigue, and 1RM bench press. Both rehydration beverages are commercially available products which were matched for carbohydrate content (Table 2).

Table 2 *Beverage Energy and Electrolyte Composition*

	Placebo	K^+
Calories	296 kcals·L^{-1}	296 kcals·L^{-1}
CHO	7.6%	7.6%
Sugar	76g·L^{-1}	76g·L^{-1}
Sodium	0 mmol·L^{-1}	3.7 mmol·L^{-1}
Potassium	0 mmol·L^{-1}	38 mmol·L^{-1}

Strength, blood, and body mass were measured at three time points during each experimental trial: upon arrival to the lab in a euhydrated state (EUH), post dehydration (HYP), and post rehydration (RHY) (Figure 1). In order to normalize fatigue throughout each 1-RM attempt, participants followed the same load progression as the euhydrated condition of their first experimental trial. At least a week later, participants returned to the lab for their second experimental trial and repeated the testing protocol but received the rehydration beverage which was not consumed during their first experimental trial.

Biochemical Analysis

Hydration status was measured at three points per experimental trial (EUH, HYP, RHY) via blood samples used to measure changes in plasma volume. Blood samples were collected in lithium-heparin tubes at three time points: before dehydration, after dehydration, and after rehydration. Hemoglobin was measured using the cyanmethemoglobin method (57). Hematocrit was measured in triplicate using microcentrifugation, then corrected by multiplying by 0.96 to correct for plasma trapped with the packed red cells and multiplied by 0.93 to correct for venous to total body HCT ratio (28). These values were then used to determine each participant's changes in plasma volume using the methods of Dill and Costill (28):

$$BV_A = BV_B(\frac{Hb_B}{Hb_A})$$

$$CV_A = BV_B(Hct_A)$$

$$PV_A = BV_A - CV_A$$

$$\Delta\, BV, \% = 100(BV_A - BV_B)/BV_B$$

$$\Delta\, CV, \% = 100(CV_A - CV_B)/CV_B$$

$$\Delta\, PV, \% = 100(PV_A - PV_B)/PV_B$$

Subscripts B and A refer to before and after dehydration, respectively. Hematocrit (Hct), hemoglobin (Hb), blood volume (BV), red cell volume (CV), and plasma volume (PV) were included in the equations. BV_B =100. All plasma volume changes were calculated in reference to the initial hemoglobin and hematocrit measurements taken during each participant's first experimental trial, as has previously been described (56).

Whole body fluid balance was also measured via change in body mass before and after dehydration, as well as following rehydration. Any urinary losses throughout each experimental trial were also collected and weighed to compare the water retention between consumption of each beverage.

Beverage Rating

During the rehydration period, participants also completed a visual analog scale (see APPENDIX B) in which they rated the beverage on palatability, the likelihood they would choose this drink for rehydration, sweetness, and appearance. Participants drew a straight line on the scale that represented their rating for each beverage. These were measured via ruler along the scale and divided by the total length of each rating line to determine percent values for each question.

Statistical Analysis

A two-way repeated measures ANOVA (Drink x Time) was used for analysis of each dependent variable for hydration, strength, and fatigue. The main effect of Time and the interaction of Drink x Time were the primary outcomes of interest. Dependent variables included maximal bench press, peak torque extension and flexion at each isokinetic speed, percent fatigue during the 50-contraction fatigue test, relative change in plasma volume, change in body mass, and urine output following the start of the rehydration period. All statistical analyses were completed using Sigmaplot 12.5 (Systat Software Inc.). Significance was set at 0.05. Where a significant main effect or interaction was found, the Holm-Sidak post hoc test was used for multiple comparisons.

CHAPTER 4. RESULTS

Hydration

Body Mass

Average time spent in the environmental chamber was 106 ± 25 min across both conditions. There was no significant difference in time spent dehydrating in the environmental chamber between trials ($p > 0.05$). We observed a significant main effect of time on body mass across each experimental trial (Figure 2). On average, hypohydrated (HYP) body mass was approximately 2.42 kg lower than pre-exercise body mass with a mean 2.8 ± 0.1% dehydration across all trials. Following 2 hours of RHY with $1L \cdot kg^{-1}$ fluid consumption, body mass was still significantly lower than pre-dehydration values ($p < 0.05$) by 0.7 ± 1.3 kg (~0.8%). There was no significant interaction of Drink x Time on the restoration of body mass when half of the fluid consisted of a flavored sugar water placebo or a high potassium sports drink ($p < 0.05$). Total fluid volume ingested throughout rehydration was on average 2.40 + 0.09 L (Placebo) and 2.42 ± 0.09 L (K^+). Throughout rehydration, there was no significant difference in the amount of calories or sugar consumed during either trial for the first two boluses (0 and 30 minutes). Total kcals consumed were on average 355 ± 13 for the placebo and 358 ± 13 for the high potassium sports drink. Potassium consumption was significantly greater in the K^+ condition, with 46 ± 1.7 mmol K^+ coming from this beverage compared to 0 mmol K^+ in the placebo.

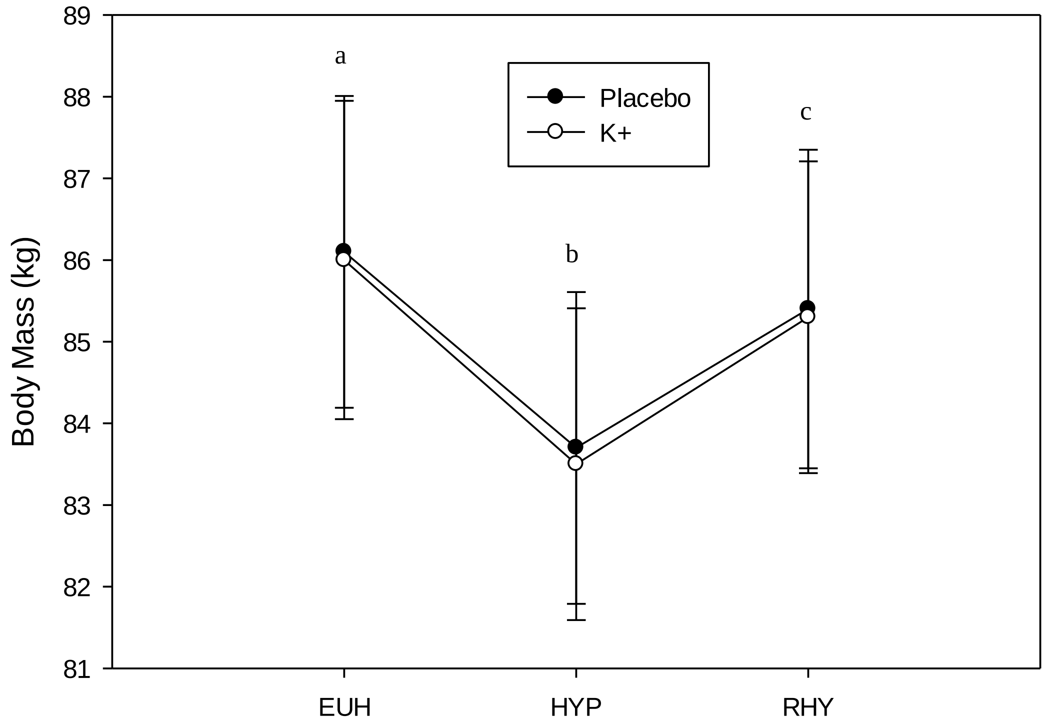

Figure 2 Average body mass changes throughout each experimental trial.
[abc]Time points with different letters are significantly different. Values are means ± SE, p <0.05 n=10.

Plasma Volume

There was a significant main effect of Time on plasma volume changes ($p < 0.001$), with a significant mean decrease in plasma volume following dehydration of approximately 12.7 ± 2.1% across both trials using the methods of Dill and Costill (Figure 3). There was no significant interaction effect of Drink x Time during this rehydration period ($p > 0.05$). Calculated plasma volume during RHY was not significantly different from EUH.

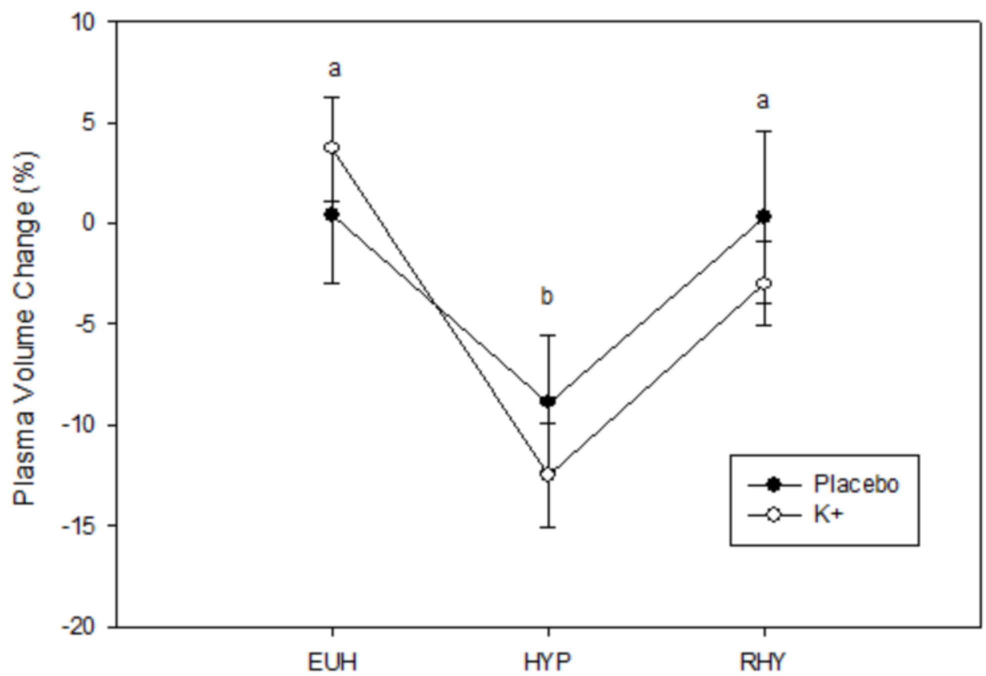

Figure 3 Plasma volume changes with dehydration and rehydration with two different drinks. [abc]Time points with different letters are significantly different. Values are means ± SE, $p < 0.05$, n = 10.

Urine Output

Urine output was significantly different throughout the RHY period ($p < 0.05$), with an average urine output of 375.1 g during this time period. However, there was no significant interaction of Drink x Time on the cumulative urine output during rehydration ($p > 0.05$).

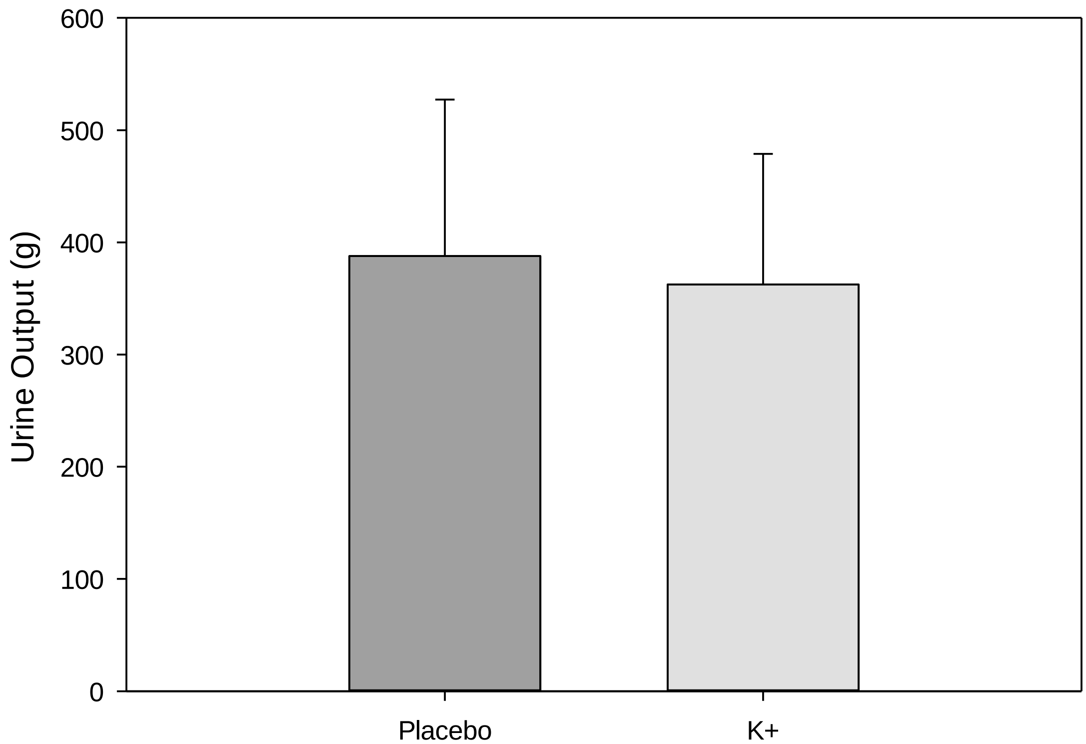

Figure 4 Cumulative urine output following rehydration. Values are means ± SE. There was no significant difference between drinks, $p > 0.05$, $n = 10$.

Performance

Bench Press

There was a significant main effect of Time ($p < 0.05$) on bench press performance, with HYP performance significantly decreased compared to pre-exercise performance. On average, bench press performance decreased approximately 5 ± 2.2% across each dehydration trial. Rehydration with either beverage did not significantly restore bench press performance to pre-dehydration values, with bench press still 1.9 ± 2.7% less than EUH. There was no significant interaction effect of Drink x Time on this result ($p > 0.05$).

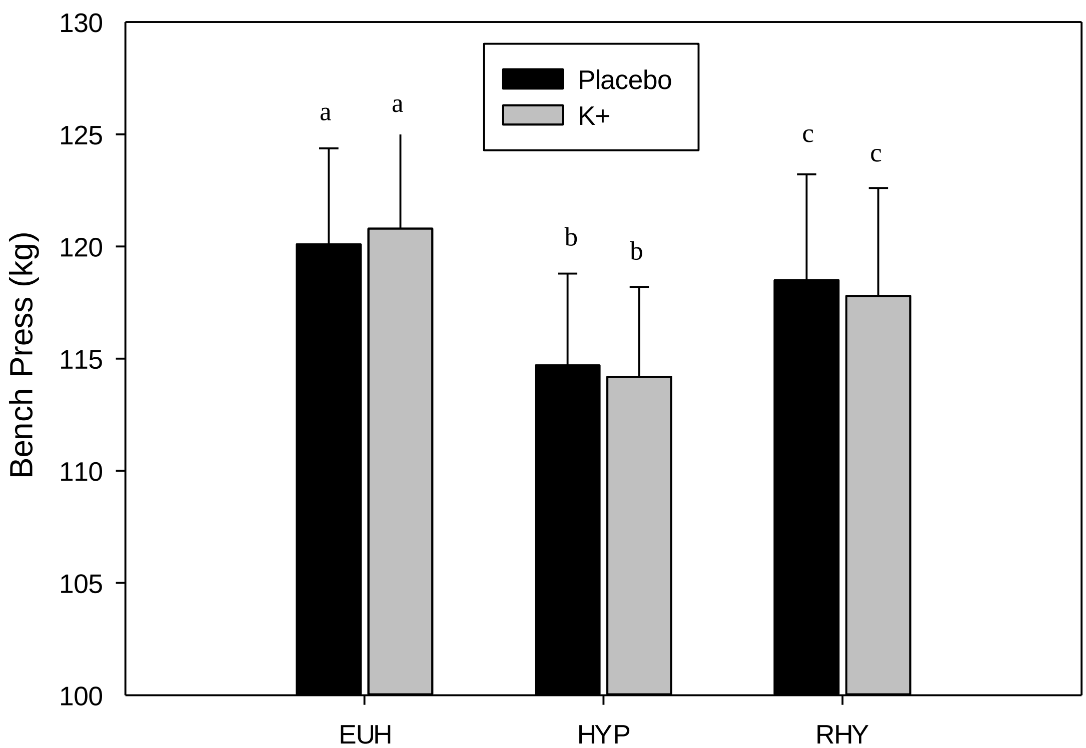

Figure 5 Change in 1-repetition maximum (1-RM) bench press. Data presented as means ± SE. [abc] Values with different letters are significantly different, $p < 0.05$, $n = 10$.

Isokinetic Peak Torque

At 60 deg·s^{-1} there was a significant decrease in knee extension peak torque with dehydration ($p < 0.05$). This amounts to an average decrease between each experimental trial of 8.2% with hypohydration. With rehydration, there was no significant difference in isokinetic extension compared to the dehydrated value ($p > 0.05$). There was not a significant effect of Time ($p > 0.05$) during knee flexion at this speed.

There was no significant effect of Drink x Time on any of the changes in isokinetic strength during rehydration ($p > 0.05$) at faster speeds (120 deg·s^{-1} or 240 deg·s^{1}). However, there was a significant main effect of Time at 120 deg·s^{-1} between the EUH and RHY conditions ($p < 0.05$) (Figure 8).

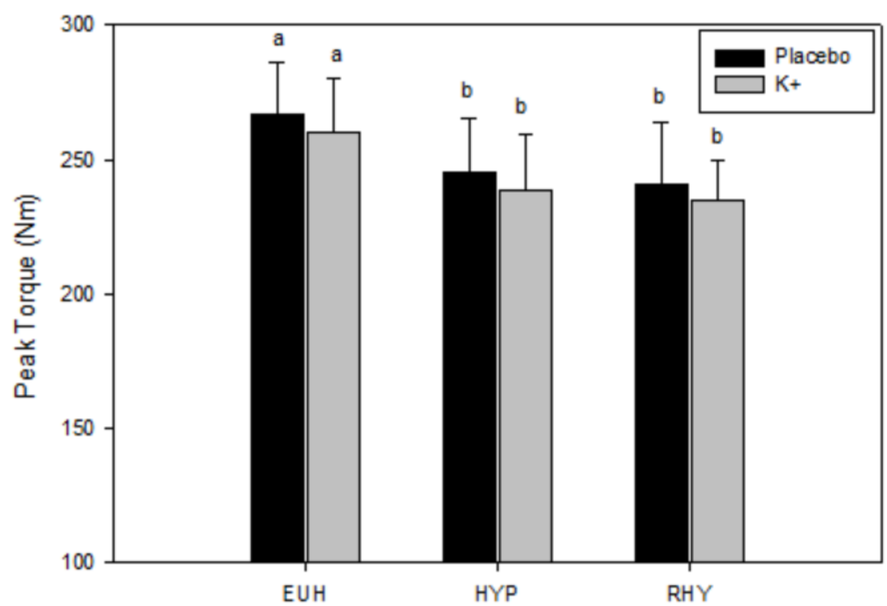

Figure 6 Effect of each drink at each stage of dehydration/rehydration for isokinetic extension peak torque at 60 deg·s^{-1}. Values are means ± SE. ^{abc}Values with different letters are significantly different, $p < 0.05$, $n = 10$.

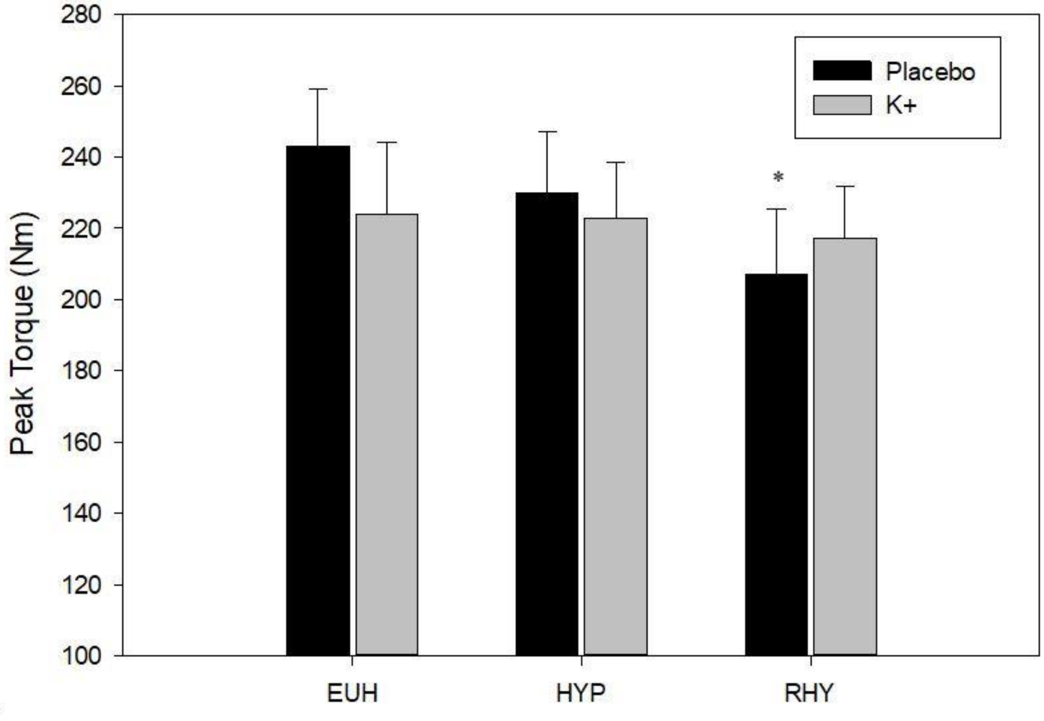

Figure 7 Effect of each drink at each stage of dehydration/rehydration for isokinetic extension peak torque at 120 deg·s^{-1}. * denotes significantly different from EUH. Values are means ± SE, $p < 0.05$, $n = 10$.

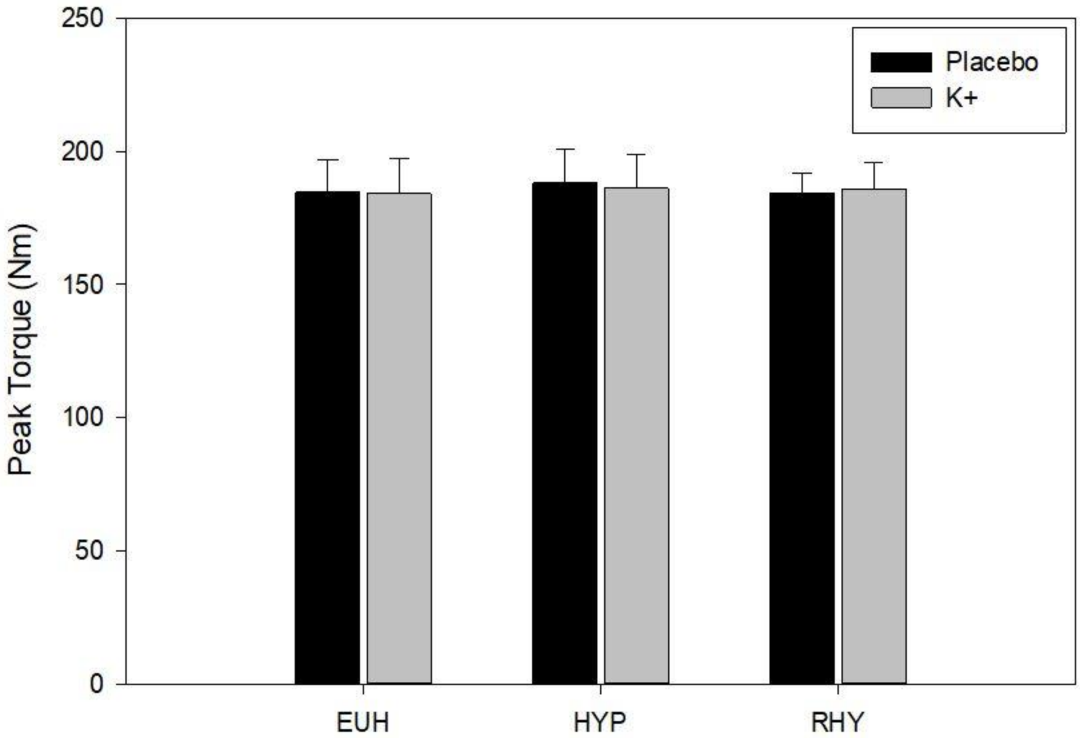

Figure 8 Effect of each drink at each stage of dehydration/rehydration for isokinetic extension peak torque at 240 deg·s^{-1}. Values are means ± SE. There was no significant difference in values for drink or time, $p > 0.05$, $n = 10$.

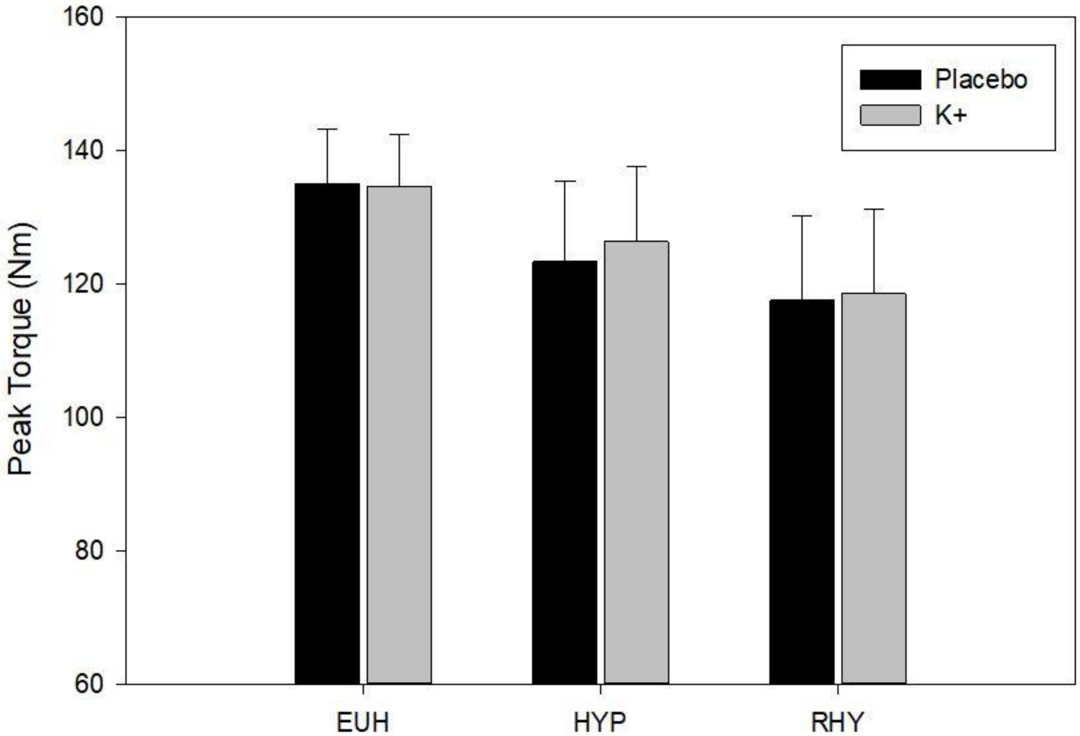

Figure 9 Effect of each drink at each stage of dehydration/rehydration for isokinetic flexion peak torque at 60 deg·s^{-1}. Values are means ± SE. There was no significant difference in values for drink or time, $p > 0.05$, $n = 10$.

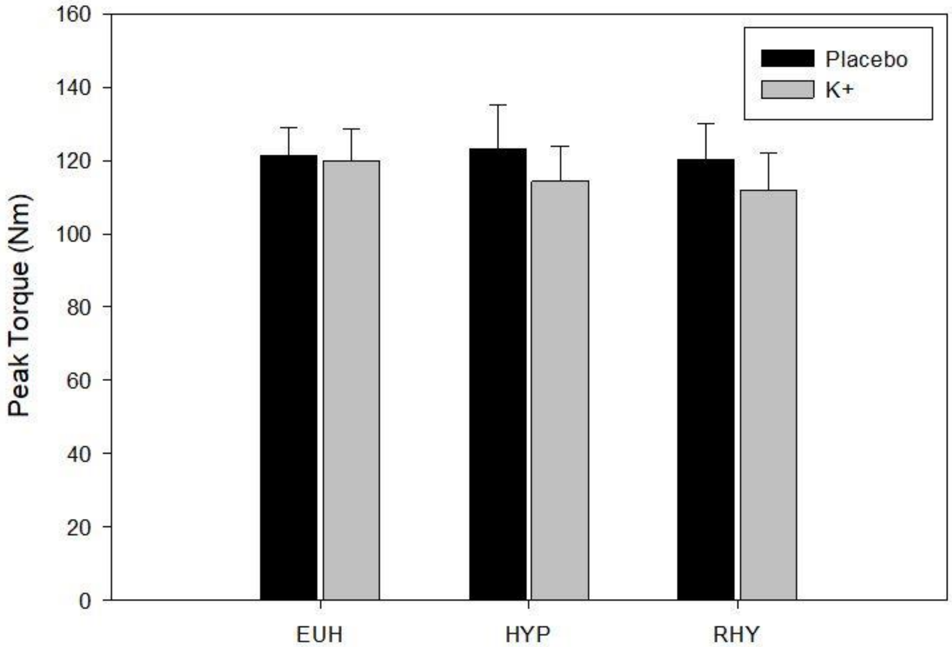

Figure 10 Effect of each drink at each stage of dehydration/rehydration for isokinetic flexion peak torque at 120 deg·s^{-1}. Values are means ± SE. There was no significant difference in values for drink or time, $p > 0.05$, $n = 10$.

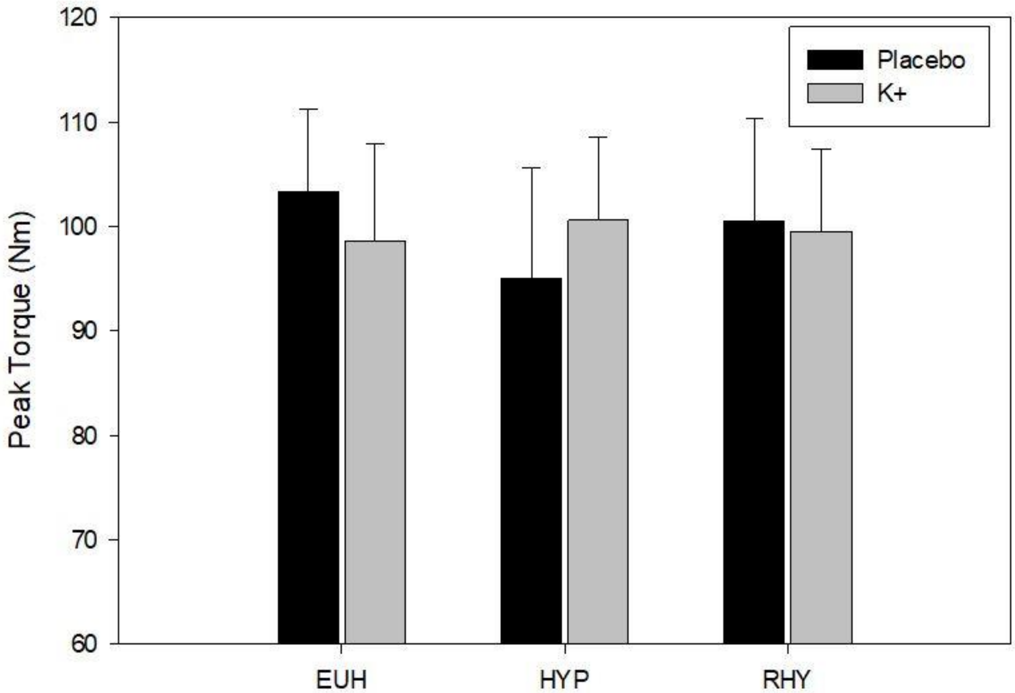

Figure 11 Effect of each drink at each stage of dehydration/rehydration for isokinetic flexion peak torque at 240 deg·s^{-1}. Values are means ± SE. There was no significant difference in values for drink or time, $p > 0.05$, $n = 10$.

Fatigue

There was no significant interaction of Drink x Time on leg extensor fatigability throughout the trials. There was a significant main effect of Time ($p < 0.05$) on mean torque during the 50-contraction fatigue test. Performance during this test decreased on average 10.5 ± 2.8% for each trial. Mean torque during RHY was not significantly different from HYP ($p<0.05$).

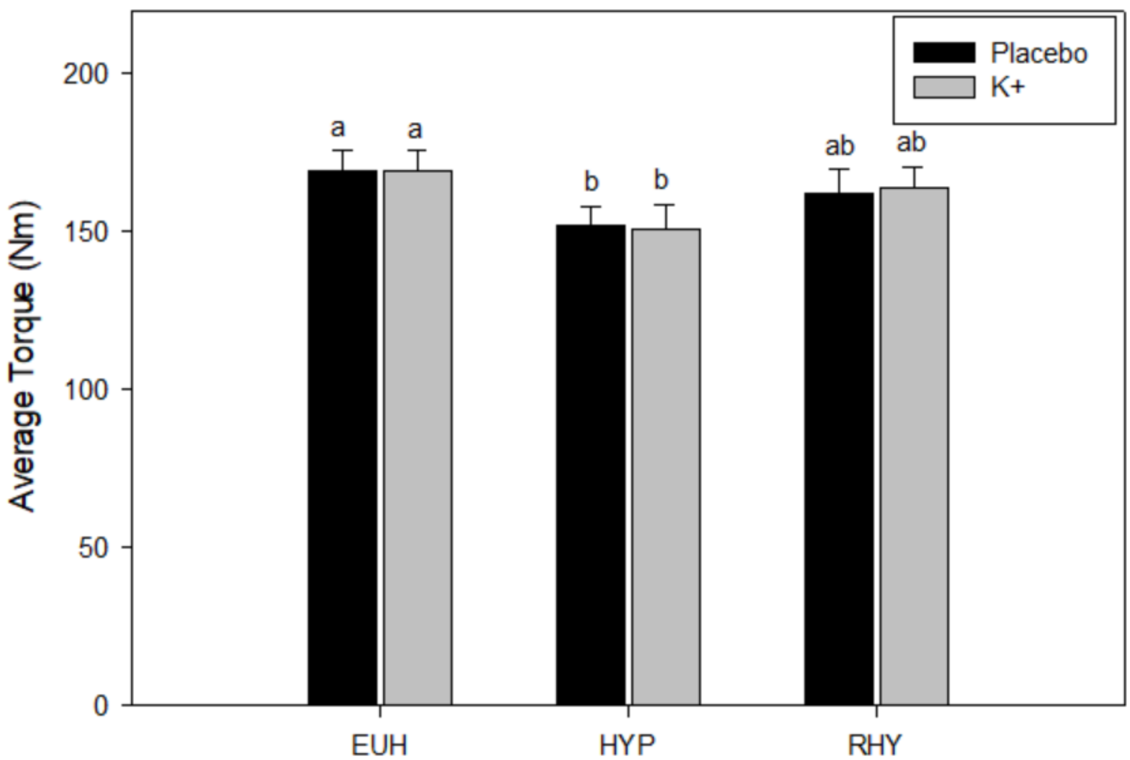

Figure 12 Effect of hydration state on knee extensor fatigability during a 50-contraction fatigue test.Values are means ± SE. [ab]Values with different letters are significantly different, $p < 0.05$, n = 10.

Beverage Rating

For the visual analog scale on beverage rating, there were no differences in subjective ratings of each rehydration beverage for palatability, likelihood to use for rehydration, sweetness, or appearance ($p > 0.05$).

CHAPTER 5. DISCUSSION

The main finding of this study was that ~3% exercise and heat-induced dehydration impairs both bench press 1-RM and isokinetic knee extension peak torque at 60 deg s^{-1} in resistance trained males. This strength deficit was not completely recovered despite two hours of complete rehydration with fluids consumed in an amount equal to $1L \cdot kg^{-1}$ body mass lost during dehydration. Neither a high potassium sports drink nor flavored sugar water were effective in the restoration of performance or hydration status when provided as half of the rehydration fluid.

The results of this study confirm previous findings that dehydration impairs muscular strength when tested via maximal bench press as well as isokinetic knee peak torque leg extension at 60 deg s^{-1}. In the present study, the decline in bench performance of 5% was similar to the decline observed by Schoffstall of about 5.6% (16), despite the greater magnitude of dehydration achieved by participants in the present study (1.5% vs. 2.8% dehydration). While participants in the study by Schoffstall were able to overcome the strength deficit incurred by 1.5% dehydration, the attempt at fluid recovery utilizing $1L \cdot kg^{-1}$ was not sufficient to restore baseline bench press strength in our participants when closer to 3% dehydration was achieved. Both the present study and the study completed by Schoffstall incorporated a 2 hour rehydration window, as consistent with the allotted timeframe between weigh-in for competition for powerlifting and wrestling events. Though Schoffstall permitted subjects to rehydrate through ad libitum water consumption, our study included set intervals for rehydration in an amount equal to $1L \cdot kg^{-1}$ body mass lost during dehydration. There was not a significant difference in subject body mass from pre-hydration values following rehydration in their study. It is also important to note the measurements used for the euhydrated condition by Schoffstall took place on a separate day, whereas in our study morning bench press performance was utilized as a measure of euhydrated muscular strength. It is therefore surprising that we observed similar declines in strength with a greater level of dehydration, in addition to testing occurring immediately after the bout of exercise-dehydration.

We observed a significant decrease in peak extension torque of the dominant limb at 60 deg s^{1}. The unobserved decline at faster isokinetic speeds (120 and 240 deg·s^{-1}) with dehydration is consistent with the results of Hayes and Morse (58). They observed a decline in peak torque at a slower 30 deg·s^{-1} but not at 120 deg·s^{-1} after participants reached 3.9% body mass loss. Our study also measured performance at 240 deg s^{-1} and did not detect any decrements in strength. Based on results from these studies, we would expect peak torque at 30 deg s^{-1} may have declined in the present study if it were included as an additional testing speed. Perhaps declines in peak torque at higher velocities require a greater level of dehydration. When our lab tested wrestlers dehydrated 5% of body mass, they experienced a significant decline in peak torque at slow and fast isokinetic speeds. Perhaps in our present study, since participants were only dehydrated 2.82% of body mass, they may not have reached a sufficient level of hypohydration to impair performance at these faster isokinetic speeds. This will require further investigation into the effect of varying levels of dehydration on performance at different isokinetic speeds. Interestingly, this effect was not observed for peak flexion at any of the isokinetic speeds, although there was a trend for a decline at 60 deg·sec^{-1}. It is unclear why flexion was not impacted as profoundly as extension, but this may relate to participants being more familiar with the extension motion.

Muscular fatigue measured via the 50-contraction fatigue test of the dominant knee was significantly different across time, but not between the two rehydration conditions. Average torque throughout the test decreased with dehydration but was completely recovered with rehydration with either beverage. These findings are similar to current evidence suggesting there is an approximate 8.3% decline in muscular endurance with dehydration (14).

There was no significant difference between the two beverages on any of the performance outcomes observed in this study. Although we did not directly measure intracellular water levels in this study, considering the non-significant differences in body mass changes and urine output between the drinks, it is less likely there was a differential restoration of the intracellular fluid space when subjects consumed the high potassium beverage, as has previously been suggested but not confirmed (38, 40, 42). The beverage used our study was also lower in its potassium content (38 $mmol \cdot L^{-1}$) compared to the 51 $mmol \cdot L^{-1}$ used in Nielsen's study (42), which may have contributed to the insignificant differences between conditions. While Nielsen administered a set volume of fluid for all participants (2700 mL), in our study we provided fluids based on total body mass during dehydration and provided half as the rehydration fluid. Because of the lower potassium content and the lower total fluid volume, it is possible there may be a higher threshold before potassium seems to exert an effect on intracellular fluid restoration. However, these findings require further investigation using a more direct marker of intracellular hydration status, as Nielsen's study based estimation of intracellular water changes based on urinary and plasma sodium balance. In Nielsen's study there was also significantly greater sugar content in the sugar water drink used in their study compared to the high potassium drink. In the present study we attempted to isolate the effect of potassium on fluid balance, since carbohydrate content can also influence fluid balance (62).

We must acknowledge some of the additional components in the high potassium sports drink. Because we utilized a commercially available beverage rather than a lab created high potassium formula, we were unable to control for the additional components in the sports drink. These components included Vitamin A, Vitamin C, Vitamin E, Niacin, Vitamin B_6, Folic Acid, Vitamin B_{12}, Magnesium, Pantothenic Acid, and Zinc. Currently, it does not seem these nutrients impact hydration status, but this requires further study. Magnesium plays a role in skeletal muscle function, but supplementation of this nutrient does not seem beneficial for muscle strength in those who do not have a deficiency (63).

Due to an unforeseen delay in processing the hemoglobin values for the last three subjects, as well as speculation of technician error in some initial hemoglobin measurements, hematocrit changes alone were also used for the estimation of plasma volume using the methods of van Beaumont (64):

$$\%\Delta PV = \frac{100}{100 - Hct_{pre}} \times \frac{100(Hct_{pre} - Hct_{post})}{Hct_{post}}$$

Using this alternative method, there was also a significant main effect of Time on plasma volume changes, $p<0.05$ (see APPENDIX A). Plasma volume decreased an average of 7.6 ± 1.5%. Plasma volume levels remained 2.1 ± 1.7% below EUH during rehydration. There was no significant effect of Drink x Time on the change in plasma volume. This is in contrast to findings with the Dill and Costill method in which we found RHY plasma volume was not significantly different from EUH. Though there are discrepancies between this method and the Dill and Costill method for the RHY period, we can still conclude plasma volume levels were significantly decreased during HYP and whole body fluid balance was not completely recovered with rehydration. The latter we can conclude based on the average body mass measurements remaining significantly below baseline.

Limitations

Some limitations of this study include potential familiarization with the strength testing protocols as the study progressed. This was mediated by counterbalancing the visit order for the rehydration protocols as well as inclusion of the familiarization trial. The lab environment may also limit the external validity of this study, but the inclusion of the more sport-specific measures of strength (bench press 1-RM) in a gym environment was used to offset this potential limitation.

If participants were accustomed to drinking commercial sports drinks, it is possible they may have been able to guess their test beverage during the experimental trials. In an attempt to reduce this likelihood, an orange flavor was used for each experimental beverage. In our beverage questionnaire we also did not have participants rate feelings of bloatedness, which would have been beneficial to compare considering the increased bloated feelings previously observed with coconut water consumption (4). Variations in baseline hydration status could potentially have impacted results, but to offset this chance we included the dietary record and requested that participants adhere to their intake prior to each experimental trial.

In this study we also did not include a true water control but rather matched the carbohydrate content between the two beverages. This decision was made to rule out the potential role of carbohydrates/sugar influencing the change in exercise performance associated with each of the beverages due to the additional energy consumed between the overnight fasting period and testing. However, we cannot definitively conclude whether the slight (yet non-significant) rise towards baseline performance on bench press was due to the carbohydrate or water intake. Because performance in the bench press was still significantly diminished following the rehydration period, we suspect this was most likely due to dehydration since body mass remained below initial euhydration values. Future studies should directly compare water, sugar water, a high potassium, and a high sodium beverage related to muscular strength, similar to Nielsen but while also controlling for any performance decrements incurred by fasting, repetitive testing, or the dehydration protocol itself (42).

It should be acknowledged that in matching carbohydrate content between the beverages, we may have masked any inherent advantage the high potassium sports drink may confer compared to plain water. Due to the known role of insulin in stimulating cellular potassium uptake (65) the rise in insulin levels following the acute high sugar boluses included in the present study may have contributed to any expected shifts in electrolyte and water balance. This may have prevented us from observing any significant difference in plasma volume between the drinks.

We must also acknowledge residual fatigue from repeated testing bouts over the course of each experimental trial may have influenced the declines in performance for the bench press and knee extension at 60 $deg{\cdot}s^{-1}$. Regardless, this decline may still have implications for performance throughout a complete resistance training session, as has previously been suggested (20, 21).

Future Directions

College-aged, resistance trained males were used in this study, who likely have a higher percentage of lean body mass. This in itself may contribute to the degree of intracellular and extracellular dehydration experienced, and perhaps the magnitude of strength loss (16). Additional research should examine the effect of dehydration on fluid compartments in people of different body compositions, such as obese, the elderly, and females. Future studies should also examine the influence of whole foods of varying water and electrolyte content consumed in the rehydration period on restoration of each fluid compartment as well as muscular performance (66). It would also be interesting to explore the impact of chronic dehydration throughout resistance exercise performance on muscular adaptations. The present study may also warrant expansion while addressing present methodological limitations such as lack of a water control group and perhaps attempting rehydration completely from the test beverage rather than a combination of beverage and water.

Conclusion

This study found exercise- and heat-induced dehydration of approximately 3% of body mass impaired muscular strength during bench press and isokinetic knee extension at 60 $deg \cdot s^{-1}$. This performance deficit was not overcome by rehydration with either a high potassium sports drink or a sugar water placebo when matched for energy content and when fluids were given equal to 1 $L \cdot kg^{-1}$. Muscular strength at faster isokinetic speeds was not affected by this level of exercise dehydration. Muscular endurance was also impaired when in a state of ~3% hypohydration. In order to maximize muscular strength performance, exercisers should begin resistance training sessions in a state of euhydration.

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APPENDIX A. ADDITIONAL DATA

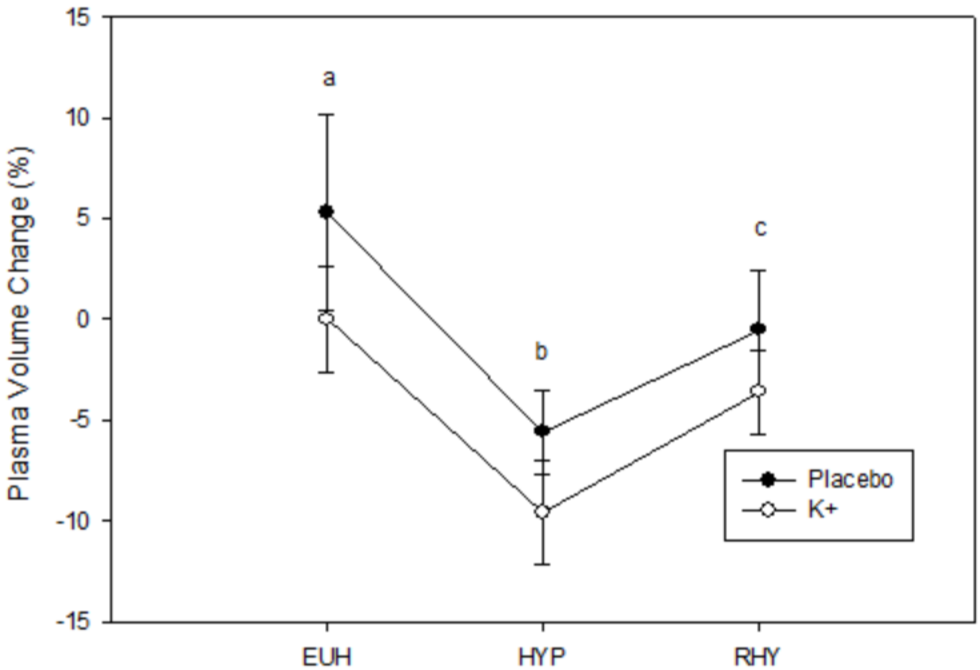

Figure A1 Percent change in plasma volume using van Beaumont method.[abc]Time points with different letters are significantly different from each other, $p < 0.05$, $n = 10$.

APPENDIX B. BEVERAGE RATING SCALE

For each question, draw a straight line along the scale that most closely reflects your opinion.

I like the flavor of this beverage…

←——————————————————→

Not at all — A lot

I would use this to rehydrate…

←——————————————————→

Never — Always

The sweetness of this beverage is…

←——————————————————→

Not sweet enough — Just right — Too sweet

The appearance of this beverage is…

←——————————————————→

Unappealing — Very Appealing

APPENDIX C. IRB APPROVAL MEMO

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Institutional Review Board
Office for Responsible Research
Vice President for Research
2420 Lincoln Way, Suite 202
Ames, Iowa 50014
515 294-4566

Date: 04/06/2018

To: Mitchell E Zaplatosch Rick Sharp

From: Office for Responsible Research

Title: **The Effect of Dehydration and Rehydration with a High Potassium Beverage on Muscular Strength and Power in Collegiate Males**

IRB ID: **18-124**

Submission Type: Initial Submission **Review Type:** Full Committee

Approval Date: 04/03/2018 **Date for Continuing Review: 04/02/2020**

The project referenced above has received approval from the Institutional Review Board (IRB) at Iowa State University according to the dates shown above. Please refer to the IRB ID number shown above in all correspondence regarding this study.

To ensure compliance with federal regulations (45 CFR 46 & 21 CFR 56), please be sure to:

- **Use only the approved study materials** in your research, including the **recruitment materials and informed consent documents that have the IRB approval stamp**.
- Retain signed informed consent documents **for 3 years after the close of the study,** when documented consent is required.
- **Obtain IRB approval prior to implementing any changes** to the study.
- **Inform the IRB if the Principal Investigator and/or Supervising Investigator end their role or involvement with the project** with sufficient time to allow an alternate PI/Supervising Investigator to assume oversight responsibility. Projects must have an eligible PI to remain open.
- **Immediately inform the IRB of** (1) **all serious and/or unexpected** adverse experiences involving risks to subjects or others; and (2) **any other** unanticipated problems **involving risks** to subjects or others.
- **Stop all human subjects research activity if IRB approval lapses,** unless continuation is necessary to prevent harm to research participants. Human subjects research activity can resume once IRB approval is re-established.
- **Submit an application for Continuing Review** at least three to four weeks prior to the **date for continuing review** as noted above to provide sufficient time for the IRB to review and approve continuation of the study. We will send a courtesy reminder as this date approaches.

IRB 03/2018