DEHYDRATION CHARACTERISTICS OF EXPERIENCED ROCK CLIMBERS USING AN INDOOR ROCK CLIMBING TREADMILL

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Brian James Conder

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APPROVAL

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Brian James Conder

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Dr. John G. Seifert

Approved for the Department of Health and Human Development

Dr. Mark Nelson

Approved for The Graduate School

Dr. Carl A. Fox

STATEMENT OF PERMISSION TO USE

Brian James Conder

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ABSTRACT

To date there are no published studies that quantify the amount of dehydration that takes place during rock climbing (RC). The purposes of this study were to determine whether significant dehydration occurs during a simulated RC session and whether *ad libitum* water ingestion augments this dehydration. In order to do so, eight male (Mean±SD; 26.5±5.8) and two female (24.0±1.4 yrs) experienced rock climbers completed two identical 115-minute RC trials on a motorized indoor RC treadmill, which consisted of six 15-minute RC intervals with a five minute rest between each interval. One trial the subjects did not receive water (NH) the other they ingested water *ad libitum* during the rest periods (AL). Percent change in body mass (%ΔBM) and percent change in plasma volume (%ΔPV) were calculated for both trials. Urine specific gravity (USG), rhythmic hand grip endurance and plasma creatine kinase were collected before and after both trials. Heart rate and rating of perceived exertion (RPE) were measured throughout both trials. Data was analyzed via RMANOVA, Wilcoxon signed-rank tests and paired T-tests. The level of significance was set at $P \leq 0.05$. There were significant differences between trials for %ΔBM (Mean±SE: NH=-2.4±0.1%, AL=-0.9±0.2%) and %ΔPV (NH=-2.93±2.42%, AL=+8.76±3.24%). Heart rate and RPE significantly increased during both trials. There was a significant interaction between trials for HR. No other significant differences between trials were observed. Significant dehydration can occur during RC when %ΔBM is used as an indicator, but not final USG. The cardiovascular stress associated with this dehydration was decreased by *ad libitum* water ingestion.

CHAPTER ONE

INTRODUCTION

At its inception, rock climbing (RC) was a skill required of mountaineers to successfully scale mountain peaks (Frison-Roche and Jouty 1996). Rock climbing has since evolved from a necessary mountaineering skill to a popular sport that has national and international organizations, such as the International Federation of Sport Climbing (IFSC) and USA Climbing, which administer amateur and professional level competitions. Thus, the popularity of RC has grown to the point that RC can no longer be placed into a single athletic discipline.

In order to have a proper perspective, one must account for a wide range of athletes, conditions, equipment, and techniques. For example, two dramatically different techniques include free and sport climbing. In free climbing, climbers ascend rock faces with no pre-placed protection equipment, while sport climbing uses permanent protection such as bolts in the rock face and allows for more gymnastic movements and positions (Giles, Rhodes, and Taunton 2006).

The development of RC, as an athletic discipline, has brought forth research on the physiology of RC. However, according to Watts (2004), the majority of research on the physiology of RC has been limited to multiple two to seven minute climbing bouts interspersed with rest periods between climbing bouts. This research, however, fails to account for endurance RC athletes who climb large rock faces, sometimes 300 vertical meters (≈1000 ft) or more, and mountaineers who climb most of the day for multiple days

(MacDonald, Green, Naylor, Otto, and Hughson 2001). With these sustained bouts of physical activity, it must be asked, how do RC endurance athletes stay adequately hydrated?

Hydration

All rock climbers have the same primary goal of safely reaching the top of a rock face. This is accomplished by bouts of intermittent activity punctuated by periods of sustained isometric muscle contraction (Billat 1995), which have a metabolic requirement ranging from 24 to 33 $ml \cdot kg^{-1} \cdot min^{-1}$ (Giles et al. 2006). These vigorous-intensity metabolic rates lead to an increase in body temperature and sweat rate, eventually leading to body water losses and, ultimately, dehydration (Sawka et al. 2007). However, RC athletes often limit the amount of weight they carry which leads to the dilemma of limiting an essential item, water. Climbers must carry sufficient water to minimize dehydration, but not so much that movement is restricted. Thus dehydration and significant decreases in athletic performance are inevitable without adequate water intake (Sawka et al. 2007).

Researchers have found that adequate hydration is imperative for optimumizing athletic performance. In a review, Noakes (1993) reported that dehydration of 2 to 4% of body mass can lead to decreases in athletic performance due to an increase in physiological stress as measured by heart rate, core temperature, and rating of perceived exertion (RPE). If the activity continues and dehydration increases in severity, stress on the body continues to rise (Montain and Coyle 1992b). Additionally, Cheuvront, Carter, and Sawka (2003) stated that aerobic capacity is diminished when dehydration leads to the loss of more than two percent of total body weight. Moreover, it has been reported that dehydration significantly impairs resistance exercise performance (Kraft et al. 2010) and substantially increases oxidative stress after resistance exercise (Judelson et al. 2008). From the wealth of available research, it is clear that dehydration is a hindrance to exercise performance.

There is not a well established benchmark for how much water a climber should carry during an outing. Because of the difficulty of carrying large amounts of water, there is a tendency for climbers to carry insufficient water to minimize dehydration. For instance, in R. C. Aleith's book *Bergsteigen: Basic Rock Climbing*; he states that, "two quarts of water a day is sufficient under normal conditions" (1971, pg. 9). However, there is a possibility that rock climbers can sweat two quarts (1893 mL) of water after as little as two hours of rock climbing. Published sweat rates for other activities, such as running, cycling, swimming, etc., range from 0.29 L/hr to up to 2.6 L/hr (Sawka et al. 2007). If an estimated sweat rate of 1 L/hr is used for RC, then RC athletes will sweat out more liquid in two hours than they carry for an entire day. Pilot data collected in the Montana State Univeristy Movement Science Lab did not measure sweat rates, but substantiated the idea that rock climbers can potentially become dehydrated during a rock climbing session. In that study, the subjects climbed for one hour on a RC treadmill. Each subject ingested at total of 450 ml of water during the climb and another 150 ml after the climb was finished. Subjects lost 0.61% of body mass over the course the hour long climb, and after adjusting for water intake the loss would have been 1.4%. At this rate of exertion, even with a hydration plan of 600 ml of water per hour of rock climbing, a 2% decrease in body weight would be reached in a little less then two and a half hours.

Since dehydration causes a decrease in exercise performance and appears to be possible during RC, a hydration strategy is required. Traditional hydration strategies (Convertino et al. 1996) suggested replacing fluid according to sweat loss, but more recently an *ad libitum* hydration strategy has been suggested as a starting point for endurance athletes (Sawka et al. 2007). Therefore, drinking water *ad libitum* during rest periods appears to be a logical option for rock climbers.

Significance of the Study

The popularity of RC has grown to the point that the International Olympic Committee has granted definitive recognition to the IFSC (IFSC 2010). However, rock climbers have the tendency to carry small amounts of water, and researchers have found that even small amounts of dehydration (≥2%) can negatively affect exercise performance. Given that there is currently no published data on the levels of dehydration experienced during RC, the results of this study quantified the amount of dehydration experienced due to RC on a motorized indoor RC treadmill (RC_{trd}).

Statement of Purpose

The primary purpose of this research was to determine whether significant dehydration takes place during a 115-minute RC bout on a RC_{trd}. The secondary purpose of this research was to determine whether an *ad libitum* hydration strategy significantly diminishes the physiological stress experienced during a 115-minute RC bout on a RC_{trd}.

Hypotheses

The primary hypothesis was that significant dehydration would take place during a 115-minute RC bout on a RC_{trd}.

$$\mathbf{H_0}: \mu_{PRE} = \mu_{POST}$$

$$\mathbf{H_{A1}}: \mu_{PRE(BM)} > \mu_{POST(BM)}$$

$$\mathbf{H_{A2}}: \mu_{PRE(USG)} < \mu_{POST(USG)}$$

Where $\mu_{PRE(BM)}$ and $\mu_{POST(BM)}$ = the mean body mass before and after a 115-minute RC bout on a RC_{trd}, and $\mu_{PRE(USG)}$ and $\mu_{POST(USG)}$ = the mean urine specific gravity before and after a 115-minute RC bout on a RC_{trd}

The secondary hypothesis was that *ad libitum* water ingestion would significantly decrease the physiological stress experienced during a 115-minute RC bout on a RC_{trd}.

$$\mathbf{H_0}: \mu_{NH(i,\ j)} = \mu_{AL(i,\ j)}$$

$$\mathbf{H_{A1}}: \mu_{NH(i)} > \mu_{AL(i)}$$

$$\mathbf{H_{A2}}: \mu_{NH(j)} < \mu_{AL(j)}$$

Where NH and AL = the non-hydration and *ad libitum* trials, respectively; i refers to percent change in body mass, percent change in plasma volume, exercising heart rate, 24-hour change in plasma creatine kinase, rating of perceived exertion, change in rhythmic isometric hand grip endurance and change in urine specific gravity; j refers to urine output.

Limitations

1. The researcher had no control over whether the subjects were compliant to the request to standardize their diet, abstain from strenuous exercise 24 hours before and caffeine before each RC bout, and consumed 500 mL of water 1 hour prior to the RC bouts.
2. Biological markers of hydration status fluctuate day to day, which may have affected the study's results.

Delimitations

1. This study was limited to 18 to 40 year old experienced rock climbers who reside in the Bozeman, Montana area.
2. Due to possible complications, this study was delimited to individuals who were classified as healthy according to a health history questionnaire.
3. This study was delimited to rock climbers who had more than 2 years of rock climbing experience.

Operational Definitions

VO_2 — The rate of oxygen consumption measured during a specific activity.

VO_{2max}	The highest rate of oxygen use measured during maximal physical exertion.
Core Temperature	Core temperature measured by rectal, esophageal, or other methods.
HR	Heart rate.
HR_{max}	The highest heart rate attained during a graded exercise test to volitional fatigue.
Stroke Volume	The volume of blood pumped out of the left ventricle during each cardiac cycle.
Cardiac Output	The volume of blood pumped by the heart per minute, expressed as mL/min
%ΔBM	The amount of change in body mass after an exercise bout expressed as a percentage of original mass lost.
%ΔPV	The amount of change in blood plasma due to exercise sweat loss expressed as a percentage of original plasma volume.
ΔCK	The amount of change in international units of plasma creatine kinase levels before and 24 hours after an exercise bout.
RPE	Rating of perceived exertion using the modified Borg scale.
UO	The volume of urine output expressed in milliliters.
USG	The urine specific gravity at the time of collection expressed as $g \cdot mL^{-1}$.
ΔRIHE	The change in rhythmic isometric hand grip endurance test values before and after a RC bout.
MVIC	Maximal voluntary isometric contraction.
Climbing Level	The highest difficulty route a climber has successfully finished.

ad libitum	An unprescribed hydration strategy where fluids are freely available and are ingested according to thirst.

CHAPTER TWO

REVIEW OF RELATE LITERATURE

History and Description of Rock Climbing

Though the exact origin of mountain climbing cannot be dated, early records tie this pursuit to military strategy such as Hannibal's historic 218 BC crossing of the Alps in order to invade Rome (Frison-Roche and Jouty 1996). Other records of men summiting mountains can be found throughout European and Asian history, although the purpose of these climbs is unknown (Frison-Roche and Jouty 1996). The birth of mountain climbers, originally called alpinists, came after the first successful summit attempts of Mont Blanc of the Alps in the late eighteenth century (Frison-Roche and Jouty 1996). These expeditions led to the development of the basic mountaineering techniques necessary for summiting large mountains. The development of these techniques brought about a sudden increase in efforts to summit the world's highest peaks in the name of science and exploration (Frison-Roche and Jouty 1996).

Mountain climbing eventually evolved from scientific exploration to a recreational activity. The development of recreational mountain climbing led to the separation of mountain climbing into distinct pursuits. As cited by Douglas Scott, Lito Tejada-Flores (1972) states that climbing can be separated into seven "games," these games are: 1. The Bouldering Game; 2. The Crag Climbing Game; 3. The Continuous Rock Climbing Game; 4. The Big Wall Game; 5. The Alpine Climbing Game; 6. The Super-Alpine Game; and 7. The Expedition Game. The Bouldering Game has the strictest rule set which limits climbers to only the clothing they are wearing and no other equipment. At the other end of the spectrum, the Expedition Game has no rules limiting gear, supplies, and people to accomplish a summit attempt. This review of related literature will focus on the Continuous Rock Climbing Game and the Big Wall Game, because they are most commonly referred to as RC.

The Continuous Rock Climbing Game and the Big Wall Game can require both "free climbing" or "aided climbing". Aided climbing is when ropes and other equipment, such as artificial hand holds, pitons, and slings, are used to support the climber's weight. Aided climbing techniques are often used during the Big Wall Game (Eng and Van Pelt 2010). Big wall RC expeditions often span multiple days and require climbers to ascend steep rock faces that are often over a thousand vertical feet. The most famous big wall is the 3000 foot structure named El Capitan in Yosemite National Park. Free climbing is when only the feet and hands are used to support the climber's weight; ropes are used exclusively for safety (Ament 2002). According to Eng and Van Pelt (2010), free climbing can be further separated into traditional rock climbing, which uses temporary anchors that fit into cracks that are in the rock face, and sport rock climbing which uses permanent anchors that have been drilled into the rock face.

With the advent of RC as a recreational activity, difficulty rating systems were developed in order to insure the safety of rock climbers (Ament 2002). Rating systems are diverse and vary in different countries; however, all rating systems base a route's difficulty upon the moves required and the length of the climb. Each rating system only differs in how it designates difficulty. For the sake of simplicity, only the Yosemite

Decimal System (YDS) will be explained in this review of literature since it is a very common system used by American and international climbers. The YDS is defined in Table 2.1 (Ament 2002). Within each rating class, decimal places are used to indicate a progressively increasing difficulty rating. Decimal places are not commonly used for classes 1 through 4, but are for routes above a level 5. For a comparison of rating systems refer to Appendix C.

Table 2.1. Summary description of the Yosemite Decimal System (YDS).

Rating Class	**Description**
1	Walking or Hiking
2	Moderate Scrambling
3	Simple Rock Climbing
4	Slightly More Difficult Climbing
5	Rock Climbing Where a Rope and Belay are Recommended
6	The use of Ascent Aids is Required

The Physiological Requirements of Rock Climbing

The Energetics of Rock Climbing

Physical exertion of any kind increases the body's metabolic rate above resting energy expenditure due to skeletal muscle contractions and cellular reactions. This rise in energy expenditure is predominately measured by indirect calorimetry. However, due to the difficulty of measuring energy expenditure during RC, research was limited for some time. Only in the last twenty years has the development of small portable telemetry systems allowed the study of the energetics of RC.

Due to the fact that researchers can control environmental variables indoors, most of the research on the physiology of RC has been conducted on climbers while climbing indoor RC walls. These results are not necessarily applicable to outdoor RC because indoor RC bouts are short, often only lasting four to eight minutes, while outdoor RC can range from a few minutes to an entire day interspersed with rest periods. However, researchers have overlooked this fact in favor of receiving data.

In an indoor RC study, Billat, Palleja, Charlaix, Bizzardo, and Janel (1995) measured the VO_2 of experienced rock climbers during short indoor climbing bouts, roughly 3.5 minutes, and then compared the peak VO_2 values measured during climbing to the subjects' VO_{2max} values determined by treadmill and a maximal incremental pulling test. Billat et al. (1995) reported that the subjects had a mean VO_{2max} of 54.6 ±5.2 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ via the maximal treadmill test and 22.3 ± 2.6 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ via the maximal incremental pulling test. They also reported that while indoor RC, rated at 5.13a, according to the YDS, the subjects' mean peak VO_2 was 24.9 ±1.2 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$. This equated to 45.6 % of the subjects' mean treadmill VO_{2max} and 111.7% of the subjects' mean incremental pulling test VO_{2max}. Other researchers (Bertuzzi et al. 2007; Sheel et al. 2003; Mermier et al. 1997) have found similar results with peak VO_2 values ranging from 20.1 to 38.6 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ under similar conditions, higher oxygen consumption coinciding with routes of higher difficulty. Bertuzzi et al.'s (2007) results are of most interest because they separated the results into respective energy system requirements.

They found that while climbing an easy indoor RC route the energy requirements were 39.7±5.0% aerobic, 34.0 ± 5.8% anaerobic alactic, and 26.3 ± 3.8% glycolytic. This demonstrates that RC is an intermittent physical activity that does not rely heavily on any one of the energy pathways.

A fairly modern development in the sport of RC is the RC treadmill (RC_{trd}); which allows rock climbers to climb for extended periods of time indoors. Climbing on an RC_{trd} may more closely resemble outdoor RC because the length of the route is not limited by building height. Watts and Drobish (1998) investigated the energy requirements of climbing on an RC_{trd} by testing experienced rock climbers on a non motorized RC_{trd} for 20 minutes at various degrees of inclination. The 20 minutes of climbing was separated into five 4-minute climbs with six minute rest periods between climbs. Watts and Drobish reported that the peak VO_2 measured while climbing on an RC_{trd} ranged from 29.5 to 31.7 $ml \cdot kg^{-1} \cdot min^{-1}$, which was 58.4 to 62.8% of the subjects' mean VO_{2max} measured during a maximal treadmill test. Booth, Marino, Hill, and Gwinn (1999) expanded upon this by developing a maximal protocol for a motorized indoor RC_{trd} and then measured oxygen consumption during outdoor RC. They found that experienced rock climbers had a mean VO_{2max} of 43.8 ± 2.2 $ml \cdot kg^{-1} \cdot min^{-1}$ determined by a maximal RC_{trd} protocol and a peak VO_2 of 32.8 ± 2.0 $ml \cdot kg^{-1} \cdot min^{-1}$ during outdoor RC which was 75 ± 4% of mean climbing VO_{2max}. Rodio, Fattorini, Rosponi, Quattrini, and Marchetti (2008) reported similar findings during outdoor RC, but compared the peak VO_2 values of experienced male and female rock climbers measured during outdoor RC to VO_{2max} values measured during maximal cycle ergometery. They found that experienced male and female rock climbers had a mean peak VO_2 of 28.3 ± 1.5 and 27.5 ± 3.6 $ml \cdot kg^{-1} \cdot min^{-1}$ respectively during outdoor climbing; which was 70 ± 6% and 72 ± 8% of VO_{2max} determined by cycle ergometery. Booth et al.'s (1999) and Rodio et al.'s (2008) findings bridge the gap between indoor climbing and outdoor climbing because the peak VO_2 measured during outdoor climbing (27 to 33 $ml \cdot kg^{-1} \cdot min^{-1}$) and indoor climbing (25 to 39 $ml \cdot kg^{-1} \cdot min^{-1}$) are similar. Thus, indoor and outdoor rock climbing can be judged as energetically similar activities, as long as climbing difficulty and duration are similar.

When the results presented in this review are taken into account, it can be assumed that the peak VO_2, while RC, can range from 24 to 39 $ml \cdot kg^{-1} \cdot min^{-1}$. Converting this to metabolic equivalents and then to kilocalories per minute, assuming a typical body mass of 70 kilograms, gives a caloric expenditure range of 8.4 to 11.6 $kcal \cdot min^{-1}$. This is between the estimated caloric expenditure during tennis (7.7 $kcal \cdot min^{-1}$) and cycling (12 $kcal \cdot min^{-1}$) (Brooks, Fahey, and Baldwin 2005). Further investigation into the energy requirements of outdoor climbing, specifically alpine climbing during an ultra endurance alpine race, has been conducted by Bourrilhon et al. (2009). They found that during the alpine climbing portion of the race (the race also included cross-country skiing, downhill skiing, and downhill climbing portions) the subjects had a mean energy expenditure of 54 $kilojoules \cdot min^{-1}$. This equates to 12.9 $kcal \cdot min^{-1}$, which is equivalent to jogging 6.2 miles per hour according to the American College of Sports Medicine's (ACSM) running equation for a 70 kg person (Thompson 2010). Thus, it can be said that

RC (whether indoor, outdoor, or high altitude) is an aerobic endurance activity with moderate to high levels of energy expenditure.

The Muscular Requirements of Rock Climbing

Each sport or activity has specific muscular strength and endurance requirements, and RC is no exception. Since muscular strength and endurance required during RC is difficult to measure directly, researchers instead have compared the muscular strength and endurance of rock climbers to non-climbers. Specifically, researchers have measured hand and finger strength and endurance by dynamometry, shoulder girdle strength, and endurance by pull ups and bent arm hanging.

Hand grip strength is traditionally measured as maximal voluntary isometric contraction (MVIC) using hand-grip dynamometers. Grant, Hynes, Whittaker, and Aitchison (1996) measured MVIC hand grip strength of both the right and left hands, finding that hand grip strength was not a significant attribute of rock climbers. Giles, Rhodes, and Taunton (2006) attribute this to the fact that hand-grip dynamometry does not correlate with a specific rock climbing technique. Grant el al.'s (1996) findings prompted researchers to develop different tests in order to determine the specific forearm muscular fitness requirements of RC, specifically rhythmic isometric hand grip endurance (RIHE) tests and finger strength tests.

Rhythmic isometric hand grip endurance tests were first used by Ferguson and Brown (1997) in order to compare experienced rock climbers to sedentary subjects. Ferguson and Brown's (1997) RIHE test required the subjects to hand grip at 40% of their hand grip MVIC for five seconds and then rest for two seconds and repeat until fatigue. Performance was measured as the amount of time until fatigue. Ferguson and Brown (1997) found that the rock climbers' time to fatigue was almost double the sedentary group, 853±76 sec and 420±69 sec respectively. Quaine, Vigouroux and Martin (2003) found a similar relationship when elite rock climbers and non-climbers completed a RIHE test. Quaine, Vigouroux and Martin's (2003) protocol required the subjects to hand grip at 70 to 80% of their MVIC for five seconds, and then rest for five seconds, repeating until fatigue. Performance was measured as the total number of contractions that were in the range of 70 to 80% hand grip MVIC. Quaine et al. (2003) reported that the elite climbers had a significantly greater number of contractions than the non-climbers (19 versus 12). Ferguson and Brown (1997) and Quaine et al. (2003) results establish that hand grip endurance is an important attribute for RC.

In addition to hand grip endurance, RC also requires substantial amounts of finger strength. This is due to the fact that many of the holds employed by rock climbers require the use of only the fingers (Giles, Rhodes, and Taunton 2006). Grant et al. (1996) found that recreational rock climbers had higher finger grip strength in specific positions common during rock climbing than non-climbers. They also found elite climbers had significantly higher finger strength than both recreational and non-climbers. Grant et al. (1996) results demonstrate that RC has high finger strength requirements.

Lastly, RC requires substantial amounts of shoulder girdle strength and endurance because as the difficulty or negative incline of a climb increases, the amount of body mass the upper body is required to support also increases (Birkett 1988). This attribute was demonstrated by Grant et al. (1996; 2001). Grant et al. (1996) reported that elite rock climbers had significantly greater bent arm hanging time and number of pull-ups than recreational climbers and non-climbers. Grant et al. (2001) found similar results, though lacking statistical significance in the number of pull-ups between groups. Thus, rock climbers must have substantial hand grip endurance, finger strength, and shoulder girdle strength and endurance.

The Effect of Isometric Muscle Contractions on Cardiovascular Parameters

Human motion requires muscle contraction which creates torque around joints, and the direction in which a joint turns and the type of muscle contraction that takes place is dependent upon the ratio of the torque produced by a resistance force to the torque produced by the muscle tissue (Komi 1984). If torque produced by a resistance force is less than the torque produced by the muscle tissue, a concentric muscle contraction takes place and the muscle shortens (Komi 1984). If torque produced by a resistance force is greater than the torque produced by the muscle tissue, an eccentric muscle contraction takes place and the muscle lengthens (Komi 1984). The third type of muscle contraction, an isometric muscle contraction, takes place when torque produced by a resistance force is equal to the torque produce by the muscle tissue and muscle length stays constant (Komi 1984). This is important because researchers have found that RC has substantial amounts of isometric muscle contractions.

Rock climbing has been described as an intermittent aerobic endurance activity requiring substantial amounts of isometric muscle contractions (Giles et al. 2006). This was demonstrated by Billat et al. (1995), who reported that during an indoor climb session experienced rock climbers were immobilized 36.3±9% of the total ascending time. They interpreted this to mean that RC requires substantial amounts of isometric contractions. Researchers have found that bouts of isometric muscle contractions significantly augment HR, VO_2, and blood pressure.

During dynamic exercise, cardiac output and VO_2 increase in order to meet the energy requirements of a given task. However, Kilbom and Brundin (1976) have found that HR, stroke volume and VO_2 did not follow the same pattern during isometric exercise as during dynamic exercise. Specifically, Kilbom and Brundin (1976) reported that blood pressure, HR, and VO_2 increase above baseline levels during isometric exercise, but stroke volume and arterio-venous oxygen difference did not change. When isometric hand exercise was combined with dynamic leg exercise, a similar relationship, but not as substantial, was found (Kilbom and Brundin, 1976). Kilbom and Brundin (1976) attribute the loss in stroke volume to the isometric muscle contractions restricting peripheral blood return and increased HR to the circulatory system overcoming peripheral resistance.

As reported in the energetics of RC section of this review, researchers have found that there are substantial differences between the HR and VO_2 measured during RC when compared to other activities. Billat et al. (1995), Watts and Drobish (1998), and Sheel et al. (2003) found that HR was significantly higher for a given VO_2 during RC than that measured during other activities such as running and cycling. Booth et al. (1999) attribute this difference to the isometric component of RC. Thus, there is a possibility other activities cannot be used as a comparison when trying to determine the sweat losses during RC.

The Physiological Stress Experienced Due to Dehydration

Rock climbers often spend hours hiking to a set of RC routes and then spend multiple hours actually RC (rockclimbing.com and supertopo.com internet forums, personal communications, Sep 15, 2010). This makes dehydration not only possible, but inevitable without a hydration strategy. The fact that dehydration is detrimental to exercise performance is well documented (Barr 1999; Cheuvront, Carter, and Sawka 2003; Sawka et al. 2007) and for the purpose of this literature review it will be broken into three sections: (1) effect of dehydration on cardiovascular endurance; (2) effect of dehydration on muscular fitness; (3) conclusion.

The Effect of Dehydration on Cardiovascular Endurance

Classic studies on the effects dehydration has on exercise performance were conducted for the military in preparation for combat in northern Africa during WWII. Pitts, Johnson, and Consolazio (1944) and Adolph (1947) demonstrated that hydration is required during even slight exertion in the heat. Specifically, Pitts, Johnson, and Consolazio (1944) had their subjects march on a treadmill at 3.5 miles per hour at an uphill grade for one to six hours. When the subjects were not allowed to drink water, HR, core temperature, and VO_2 increased linearly throughout the test. However, when the subjects were allowed to consume water *ad libitum*, HR and core temperature stayed relatively constant through four hours. These classic studies conducted by Pitts, Johnson, and Consolazio (1944) and Adolph (1947) were limited to long durations and low intensity marching. Not until almost the 1970s did researchers start to investigate the effects of dehydration on high intensity sport activities (Noakes 1993; Wyndham and Strydom, 1969).

The studies conducted by Pitts, Johnson, and Consolazio (1944) and Adolph (1947) focused on soldiers marching in the hot conditions. Sawka, Michael, Ronald, Knowlton, and Critz (1979) expanded upon previous research by having seven endurance trained runners run 80 minutes at 70 percent of their aerobic power, rest for 90 minutes and then repeat another 80 minute running bout identical to the first. The subjects were allowed to drink 100 mL of water during the 80 minute running bouts and 280 mL of a carbonated beverage during the 90 minute break. Sawka et al. (1979) reported that subjects lost approximately 2% of their body weight during each 80 minute running bouts and approximately 4.7% would have been lost if fluid had not been administered. They also found that rectal temperature and HR increased as exercise progressed, and that both of these variables were significantly higher during the second bout of running. Thus, applying these results to RC, as rock climbers become dehydrated and engage in repeated bouts of exercise, the amount of physiological stress compounds.

Others have continued research on how cardiovascular endurance is affected by dehydration and how fatigue can be mitigated by liquid consumption (Montain and Coyle 1992a; Montain and Coyle 1992b; Gonzalez-Alonso, Mora-Rodriguez, Below, and Coyle 1995; Gonzalez-Alonso, Mora-Rodriguez, Below, and Coyle 1997). Specifically, Montain and Coyle (1992b) had eight endurance trained cyclists exercise for two hours at 62% of maximal aerobic capacity on four different lab visits. Subjects randomly received one of four treatments; no fluid and small, moderate, and large fluid volumes. They found that when fluid was not consumed, thermal stress progressively increased, cardiac output progressively decreased, and RPE increased progressively over the two hour period. They also found that fluid ingestion attenuated all of these markers of physiological stress, and that large fluid volume had the strongest effect. Though not identical studies, Montain and Coyle (1992a) and Gonzalez-Alonso, Mora-Rodriguez, Below, and Coyle (1995) reported similar results.

In order to investigate the relationship between hyperthermia and dehydration and determine how each effect cardiovascular endurance, Gonzalez-Alonso, Mora-Rodriguez, Below, and Coyle (1997) conducted a complex study that involved having subjects exercise when hyperthermic and dehydrated, hyperthermic and euhydrated, euthermic and dehydrated, and euthermic and euhydrated. They reported that hyperthermia alone significantly reduced stroke volume (SV) and significantly increased HR by 8 ± 2% and 5 ± 1% respectively while dehydration alone significantly reduced SV and significantly increased HR by 7 ± 2% and 5 ± 1% respectively. Gonzalez-Alonso et al.'s (1997) most important finding was the magnifying affect that dehydration and hyperthermia have on each other. Stroke volume was decreased by 20 ± 1% and HR increased by 9 ± 1% when the subjects were both hyperthermic and dehydrated. Subsequently, the progressive rise in body temperature and excessive loss of body water during endurance exercise work together to bring about a reduction in cardiovascular function.

Recent research has examined the effect dehydration has on central nervous system activity. Nielsen, Hyldig, Bidstrup, Gonzalez-Alonso, and Christofferson (2001) had seven endurance trained cyclists cycle for 90 minutes under hyperthermic and euthermic conditions. They recorded many of the normal physiological stress markers and a relatively new method of measuring central drive through electroencephalographic activity (EEG). Nielsen et al. (2001) found that commonly measured physiological stress markers (HR, skin temperature, and esophageal temperature) were similar to previously published data. Their main finding was that at the beginning of activity, prefrontal cortex activity was elevated; however, as exercise progressed and dehydration increased prefrontal cortex activity declined as body temperature increased. Nielsen et al. (2001) state that this may bridge the gap between RPE and fatigue, they hypothesize that this decrease in EEG equates to increases in RPE.

The research reviewed in this section indicates the fact that endurance exercise can lead to dehydration which creates physiological stress. These different physiological stresses (increased HR, decreased SV and cardiac output, and hyperthermia) work in tandem to decrease aerobic power and cause eventual fatigue.

The Effect of Dehydration on Muscular Fitness

Since dehydration affects cardiovascular endurance, it is logical to study whether dehydration significantly impairs muscular fitness variables such as muscular strength and endurance. A study conducted by Montain et al. (1998) explored possible impairments to muscular strength and endurance due to dehydration. In their study, 10 healthy and physically active subjects performed two sets of knee extension exercise until exhaustion; once while euhydrated and once while dehydrated. They found that dehydration significantly decreased muscular endurance, by as much as 15%, but did not significantly affect muscular strength. Kraft et al. (2010) also investigated how dehydration affects muscular endurance. Ten strength trained male subjects performed two trials of a whole body resistance exercise protocol. The exercises consisted of: bench press, lat pull down, over head press, barbell curl, triceps press, and leg press. Dehydration was induced by hot water immersion. During the control trial, the subjects were not allowed to return to euhydration, while during the experimental trial the subjects replaced 100% of fluid lost. Kraft et al. (2010) found that during the dehydrated trial, both the total number of repetitions and the mean number of repetitions for each set of exercises was significantly lower than during the fluid replacement trial.

Conclusions

The studies reviewed in this section covered the effect of dehydration on cardiovascular endurance and the effect of dehydration on muscular fitness. Results from these studies illustrate how dehydration affects endurance exercise performance. As a result, dehydration can have significant affects on RC performance because RC is an endurance activity punctuated by short rest periods. Thus, dehydration hypothetically can hamper both the cardiovascular and muscular fitness required of a rock climber. Consequently, a hydration strategy should be implemented.

An *ad libitum* Hydration Strategy

As stated previously, it has been found that dehydration has a negative effect upon endurance exercise performance, and that RC can be termed as an endurance activity equivalent to jogging. Traditional hydration strategies have been to replace fluids at a rate equal to fluid loss through sweat (Convertino et al. 1996). However, with further understanding of the physiological stress experienced during endurance events and the increase in occurrences of hyponatremia due to over hydration, the ACSM has published an updated position stand on exercise and fluid replacement (Sawka et al. 2007). Sawka et al. (2007) state that, "it is difficult to recommend a specific fluid and electrolyte replacement schedule because of different exercise tasks…weather conditions, and other factors…influencing a person's sweat rate and sweat electrolyte concentration" (pg. 384). They go on to state, "individuals should develop customized fluid replacement programs that prevent excessive (<2% body weight reductions from baseline body weight) dehydration" (pg. 386). This does not provide a starting point for endurance athletes and in order to answer this question one must turn to Noakes (2003). He states that marathon runners should use an *ad libitum* hydration plan that supplies 400-500 mL/hr and adjust this range according to the athlete's specific sweat rate and the environmental conditions. Thus researchers (Cheuvront and Haymes 2001; Daries, Noakes, and Dennis 2000; Nolte, Noakes, and Van Vuuren 2010) have sought whether an *ad libitum* hydration strategy is equal to or superior than replacing for fluid losses.

First, Cheuvront and Haymes (2001) researched the effects of *ad libitum* fluid replacement on eight female distance trained runners. The subjects were required to run

30 kilometers on a treadmill at their individual best marathon race pace during three separate lab visits, each visit having different environmental conditions. The three conditions were 25°C, 17°C, and 12°C. Cheuvront and Haymes (2001) found that mean fluid consumption during the 25°C trial was significantly greater than the 12°C trial, but not the 17°C trial. The most important finding was that final rectal temperature was not significantly different between the three trials, specifically 38.7 ± 0.18°C, 38.6 ± 0.24°C, 38.5 ± 0.38 °C for the 25°C, 17°C, and 12°C trials respectively. In addition, the amount of water intake did not significantly affect the core temperature measured during marathon running. Nolte, Noakes, and Van Vuuren (2010) found similar results during a four hour march. This study required 15 soldiers to carry 20.7 kilograms during a 16.4 kilometer march at an average velocity of 5 $km \cdot hr^{-1}$ under temperate conditions. Nolte, Noakes, and Van Vuuren (2010) reported that change in body mass ranged from 0 kilograms to a loss of 1.8 kilograms with a mean loss of 1.0 ± .5 kilograms. Most importantly they found that serum sodium and plasma osmolarity did not significantly decrease and mean core temperature during exercise was 37.6°C, which is in the normal range of core temperature according to Brooks, Fahey and Baldwin (2005). Hence, the studies from Cheuvront and Haymes (2001) and Nolte, Noakes, and Van Vuuren (2010) demonstrate that an *ad libitum* hydration strategy can significantly reduce the amount of physiological stress experienced during endurance exercise. However, these two studies did not compare an *ad libitum* hydration plan with traditional hydration plans. Daries, Noakes, and Dennis (2000) made such a comparison.

In their study, Daries, Noakes, and Dennis (2000) had eight male distance trained runners complete three two hour runs. Each run consisting of 90 minutes of running at 65% of their VO_{2max} and then performing a 30-minute time trial type run. The three treatments consisted of a trial where water was ingested *ad libitum* and two trials where the subjects consumed 150 ml and 350 ml of fluid per 70 kilograms of body mass every 15 to 20 minutes. These hydration strategies translated into mean fluid intake of 0.76 ± 0.35, 0.78 ± 0.12, and 1.83 ± 0.28 L during the *ad libitum*, 150 $ml \cdot 70kg^{-1}$, and 350 $ml \cdot 70kg^{-1}$ trials, respectively. Daries et al. (2000) reported that less dehydration occurred during the 350 $ml \cdot 70kg^{-1}$ (1.2%) than either of the other trials (2.7 to 3.4% for 150 $ml \cdot 70kg^{-1}$ and *ad libitum* respectively); however, there was no significant difference between the trials and estimated decreases in plasma volume, serum potassium levels, and RPE. Most importantly they found that there was no significant difference between the three trials running speed and rates of carbohydrate metabolism during the final 30 minute performance run. Unfortunately, the distances covered during the 30 minute performance run and core temperatures were not reported. Nevertheless, Daries et al. (2000) found that having a traditional hydration strategy did not have a significant advantage over an *ad libitum* strategy.

Conclusion

It has been presented that RC is an intermittent activity approximately equivalent to running at 6.2 miles per hour. It has also been presented that rock climbers may spend anywhere from one hour to an entire day climbing interspersed with rests. Because many climbers only carry small amounts of water for an entire day of climbing, dehydration is not only possible but expected. This literature review has also confirmed that dehydration has negative effects on both cardiovascular and muscular endurance. With decreases in parameters of physical fitness, not only can rock climbers expect decreases in rock climbing performance, but also an increase in the level of danger. In order to address the question of how much water rock climbers should consume while rock climbing, research on the potential benefit of an *ad libitum* hydration strategy has been presented as a strategy to prevent dehydration during RC.

CHAPTER THREE

THESIS MANUSCRIPT

Introduction

At its inception, rock climbing (RC) was a skill required of mountaineers to successfully scale mountain peaks (Frison-Roche and Jouty 1996). Rock climbing has since evolved from a necessary mountaineering skill to a popular sport with international organizations that administer amateur and professional level competitions. This development has brought forth research on the physiology of RC, which has focused primarily on the metabolic requirements of RC and the muscular fitness and anthropometric attributes of rock climbers (Bertuzzi et al. 2007; Watts 2004; Sheel 2004; Grant 1996 and 2001; Mermier et al. 2000; Giles et al. 2006). However, there has not been a single published study that describes the amount of dehydration that takes place during RC. Since there are athletes who climb large rock faces, sometimes 300 vertical meters or more, and mountaineers who climb most of the day for multiple days, it must be asked, do RC athletes stay adequately hydrated?

All RC athletes have the same primary goal to safely reach the top of a route. This is accomplished by bouts of intermittent activity punctuated by periods of isometric muscle contractions (Billat 1995), and have a metabolic requirement ranging from 24-33 $ml \cdot kg^{-1} \cdot min^{-1}$ (Giles 2006). This increased metabolic rate may lead to increases in body temperature, leading the body to respond with an increased sweat rate in order to dissipate metabolic heat (Sawka et al. 2007). As exercise is extended, the high sweat rate leads to a loss of total body water and ultimately dehydration (Sawka et al. 2007).

Often, RC athletes limit the fluid they carry in order to decrease overall ascent weight. This technique is demonstrated by R. C. Aleith (1971), who stated in *Bergsteigen: Basic Rock Climbing* that rock climbers only need two quarts of water for an entire day under “normal” conditions. However, it is possible that rock climbers can sweat two quarts (1893 mL) of water after as little as two hours of RC. Published perspiration rates for other activities, such as running, cycling and swimming can range from 0.29 L/hr to up to 2.6 L/hr (Sawka et al. 2007). If an estimated sweat rate of 1 L/hr is used for RC, then RC athletes can easily sweat out the two quarts they have with them. Pilot data collected in the Montana State University Movement Science Lab (MSU MSL) did not measure sweat rates, but substantiated the idea that rock climbers can potentially become dehydrated during a rock climbing session. In that study, subjects climbed for one hour on a motorized indoor RC treadmill (RC_{trd}). Each subject ingested a total of 450 ml of water during the climb and another 150 ml after the climb was finished. Subjects had a mean percent change in body mass (%ΔBM) of -0.61% over the course of the hour long climb. After adjusting for water intake, %ΔBM would have been -1.4%. At this rate of exertion, even with a hydration plan of 600 ml of water per hour of RC, a 2% decrease in body weight would be reached in a little less then two and a half hours. According to Noakes (1993), dehydration of 2-4% of body mass can lead to decreases in athletic performance due to an increase in physiological stress as measured by heart rate, core temperature, and rate of perceived exertion (RPE). Consequently, a hydration strategy should be implemented in hopes of maintaining athletic performance.

To date, there is no consensus for how much water a climber should carry during an outing. Due to the difficulty of carrying large amounts of water, there may be a tendency for climbers to carry insufficient amounts of water to minimize dehydration. Traditional hydration strategies (Convertino et al. 1996) suggest replacing fluid according to sweat losses. More recently, an *ad libitum* hydration strategy has been suggested as a starting point for endurance athletes (Sawka et al. 2007). Therefore, drinking water *ad libitum* during rest periods appears to be a logical option for rock climbers. However, there is no published data to base these assumptions.

The primary purpose of this study was to determine whether a 115-minute simulated RC session on an RC_{trd} would cause significant dehydration, as measured by common markers of hydration and physiological stress. The secondary purpose of this research was to determine whether an *ad libitum* hydration strategy significantly diminishes the physiological stress experienced during a 115-minute RC session on an RC_{trd} when compared to the absence of a hydration strategy.

Methods

Participants

A total of 20 rock climbers from the Bozeman, MT metro area volunteered for this study, which were recruited via flyers and word of mouth. Only 10 of the original 20, however, completed all aspects of testing. This 10 consisted of experienced male (n=8) and female rock climbers (n=2). In order to control for menses, the female subjects completed the two experiment trials during the follicular phase of their ovulation cycle. This study was approved by the Montana State University Institutional Review Board and every participant provided written consent prior to data collection.

Study Design

A repeated-measures, cross-over design was used so that participants could serve as their own controls. The participants completed four laboratory visits (two familiarization trials and two experimental trials) in the MSU MSL. Trials were scheduled according to the participants' convenience.

Familiarization Trials: During the first visit, if not previously given, the participants provided written consent to participate in the study (Appendix A), and filled out a health history and RC experience questionnaire (Appendix B). The subjects then completed a maximal voluntary isometric contraction (MVIC) hand grip test according to the protocol described by Ferguson and Brown (1997). Following the MVIC hand grip test a single 15-minute RC interval on an RC_{trd} was completed. The protocol used during this study was preprogrammed into the treadmill's computer, which allowed the treadmill to progress through the protocol automatically. The protocol (Table 3.1) had a mean difficulty, as rated by the participants, of 5.9 according to the Yosemite Decimal System (YDS). If the subjects fell off the RC_{trd} at any time, they were instructed to get back onto the treadmill. The trials were stopped if the subject could not continue.

Table 3.1. Complete description of the rock climbing route used during this study.

Stages	**Duration (min)**	**Cumulative Climbing Time (min)**	**Degrees from vertical**	**Speed (m/min)**	**Vertical Distance Climbed (m)**
1	1	1	0	7.5	7.5
2	1	2	-10	4.5	12
3	1	3	-20	4.5	16.5
4	.5	3.5	-30	3.5	18.25
5	.5	4	+5	3.5	20
6	1	5	+5	8.0	28
7	2	7	0	7.5	43
8	2	9	-5	4.5	52
9	.5	9.5	+10	5.5	54.75
10	.5	10	+10	7.5	58.5
11	1	11	-40	3.5	62
12	1	12	+5	3.5	65.5
13	1	13	0	6	71.5
14	2	15	-5	4.5	80.5

If the subjects were able to complete the climbing bout, they then practiced the rhythmic isometric hand grip endurance (RIHE) test, which was similar to that used by Ferguson and Brown (1997). The protocol required the subjects to grip at 60-70% of their MVIC for three seconds followed by a rest for three seconds. This cycle was repeated until the subject could no longer hold 60% of their MVIC for three seconds.

During the second familiarization visit, the subjects completed three 15-minute intervals of the protocol that was explained previously. Subjects completed the RIHE test before and after the climbing trial.

<u>Experimental Trials</u>: Two identical experimental trials were completed. The second trial was scheduled no sooner than seven days after the first trial at the same time of day ± 1 hour. The experimental trials were counter balanced. The two trials were labeled as the non-hydration trial (NH) and the *ad libitum* trial (AL).

For both experimental trials, subjects were asked to drink a minimum of 500 mL of water the hour before they came in for each trial to ensure similar hydration status. They were also asked to abstain from caffeine ingestion the morning of and strenuous exercise 24-hrs before both experimental trials. Additionally, subjects were instructed to eat similar meals before and after each experimental trail and not to eat within three hours of the trial. Upon arrival, each subject was asked to void their bladder. A sample was collected and analyzed for urine specific gravity (USG). Based on USG, hydration status was determined, and for this study a USG $\leq$ 1.015 was considered euhydrated, 1.015 $<$ USG $<$ 1.02 was moderately dehydrated, and USG $>$ 1.02 was considered dehydrated (Sawka 2007).

If the subjects were moderately dehydrated they were asked to drink 500 mL of water and USG was measured again 45 minutes after the 500 mL water bolus was consumed. A new lab visit was scheduled if the subjects were still dehydrated. The trials were started if the subjects were euhydrated. This was followed by measurement of dry nude body mass (BM). Subjects were then kept in a seated position for 15 minutes, during which a 150 µL finger stick blood sample was collected from the left hand for creatine kinase (CK) analysis. Immediately following the 15-minute seated rest, a finger stick was performed on the right hand and 10 to 20 µL of blood were collected into a centrifuge tube. From this blood sample, hemoglobin (Hb) and hematocrit (Hct) measurements were determined until there were two Hb measurements within ±0.5 g/dL of each other. Next, a RIHE test was conducted, after which the subjects donned a heart rate monitor.

After all preliminary procedures were completed, subjects warmed up on the RC_{trd} for 5 minutes at a speed of 4.5 $m \cdot min^{-1}$ and 5° incline. After the warm up, the subjects stepped off the RC_{trd} and it was prepared for the RC trial. After which, the first 15-minute interval of RC was begun. Once the participants completed the first 15-minute RC interval, they stepped off the RC_{trd} and were given a 5-mintue rest, during which RPE (on the 0 to 10 Modified Borg Scale) for the climbing interval was recorded. Next, the subjects repeated the same protocol and the same data were collected during each rest period until a total of six intervals were completed, which translated into a 115-minute RC trial. The subjects then rested in a seated position for 15 minutes, after which a 10-20 µL finger prick blood sample was collected for Hb and Hct determination. After this, the participants were asked to void their bladder; from this urine sample urine output (UO) and USG were measured. Final BM was measured and subsequently followed by an RIHE test. All participants returned to the lab within 24 ± 2 hours for a 150 µL finger stick blood sample for CK analysis.

Trial administration and protocols were identical, with the exception that subjects ingested water *ad libitum* during each of the 5-minute rest periods throughout the AL trial. Four water containers were filled with one liter of a commercially available bottled water (Spring Water, Western Family Inc., Tigard, OR) and the subjects were told that sufficient water was available and to drink according to their desire. *Ad libitum* water intake was determined by measuring the remaining water in the premeasured one liter water bottles using a 500 mL graduated cylinder.

Instrumentation

A motorized indoor RC_{trd} (TheRock^{TM}, Ascent Products Inc., Bozeman, MT) was used for all of the RC trials. Urine specific gravity was determined using an electronic refractometer (Pocket Refractometer, PAL-10S, Atago CO., Tokyo, Japan) and was zeroed with distilled water before every experimental trial. Urine output was measured using a 500 mL graduated cylinder. A digital scale (BWB-800, Tanita Corp., Arlington Heights, Illinois) was used to measure BM.

Hemoglobin and Hct were determined using a hemoglobin photometer (Hemopoint H2, Stanbio Laboratory, Boerne, TX). Hematocrit was predicted by the photometer using the prediction equation: Hct=Hb x 2.94. Plasma CK levels were determined by reflectance photometry (Vitros DT60 II, Johnson and Johnson Co., New Brunswick, New Jersey). The 150 µL blood samples consisted of three 75 µL microcentrifuge tubes, which were centrifuged at ≈10,000 rpm for three minutes immediately after collection. The plasma was then micropipetted into a coded container, and stored in a freezer at -7 °C. At the conclusion of data collection, the blood plasma samples were brought to room temperature (22-23 °C) and shaken before analysis. The apparatus was calibrated using CK standard solutions prior to analysis.

Heart rate was measured using a telemetry-based heart rate monitor (RS400, Polar, Helsinki, Finland) over 15-second intervals, and was downloaded using an infrared scanner (IRDA USB Adapter, Polar, Helsinki, Finland) into analysis software (Polar Protrainer V5.0, Polar, Helsinki, Finland). The software was used to extract the 15-second average of heart rate 10 minutes into each RC interval (HR_{10min}) as well as peak heart rate during each RC interval (HR_{peak}).

A transmitter (MP36, BIOPAC Systems Inc., Goleta, CA), hand dynamometer (SS25LA, BIOPAC Systems Inc., Goleta, CA) and computer software (BIOPAC Student Lab V3.7.7, BIOPAC Systems Inc., Goleta, CA) were used during all of the hand grip tests. Rhythm during the RIHE test was kept by an electronic metronome (Zipbeat, Sabine Inc., Alachua, FL).

Room temperature and percent relative humidity (%RH) were measured before each experimental trial using a wall mounted thermometer (Weksler, Deer Park, NY) and a sling psychrometer (Red Spirit Filled, Bacharach Inc., New Kensington, PA).

Data Processing

Percent change in BM (%ΔBM), change in USG (ΔUSG) and RIHE (ΔRIHE), and 24-hour change in CK (ΔCK) were calculated using pre-and post-data. Also, water intake during the AL trial was subtracted from the change in BM in order to determine whether sweat losses were similar between trials. Percent fluid retention during the AL trial was calculated for each subject by the following:

% Fluid Retention = [(*ad libitum* fluid intake − Urine Output)/*ad libitum* fluid intake] x 100%

Percent change in plasma volume (%ΔPV) was calculated using the Hb and Hct measurements via the derivation of Dill and Costill (1974) published by Harrison et al. (1982). The equation was:

$\%\Delta PV = [(Hb_B/Hb_A) \times ((100 - Hct_A) / (100 - Hct_B)) - 1] \times 100\%$.

where Hb_B and Hb_A = hemoglobin before and after exercise, and Hct_B and Hct_A = hematocrit before and after exercise.

Data Analysis

Changes in BM, USG, CK, HR_{10min}, HR_{peak} and RPE were analyzed using two-factor (time x trial) repeated measures analysis of variance (RMANOVA). A Tukey-Kraemer post-hoc test was used for all pairwise comparisons. Due to an equipment malfunction, pre-and post-RIHE data was only available for seven subjects. Since these data were not normally distributed, Wilcoxon signed-rank tests were performed on the pre-and-post RIHE and ΔRIHE. Paired T-tests were used to evaluate whether there were differences between trials for %ΔBM, %ΔPV, ΔUSG, UO, and ΔCK. Statistical significance was established using an α level of $P \leq 0.05$.

Results

Environmental Conditions

Environmental conditions were temperate, room temperature and %RH was 22.1±1.2°C and 35.9±6.0% (Mean±SD), respectively.

Participants, Water Intake and Fluid Retention

Descriptive data is presented as Table 3.2. During the AL trial, participants had a mean water intake and percent fluid retention of 1.07±0.35L and 53.7±28.3% (Mean±SD), respectively.

Table 3.2. Summary of the descriptive data for study participants (Mean±SD).

	n	Age (yrs)	Weight (kg)	Experience (yrs)	Outdoor (YDS)†	Indoor (YDS)‡
Male	8	27±6	70.8±4.8	10±5	5.12±0.01	5.12±0.01
Female	2	24±1	60.3±1.1	5±1	5.12±0.02	5.13±0.02

†=The most difficult outdoor rock climbing route finished, following the Yosemite Decimal System (YDS).
‡=The most difficult indoor rock climbing route finished, following the Yosemite Decimal System (YDS).

Change in Body Mass

Body mass significantly decreased ($p<0.05$) during the NH trial, but not the AL trial. Percent change in body mass was significantly different between trials ($p<0.05$). Body mass data is presented as Table 3.3. After adjusting for water intake, there was no significant difference between trials for %ΔBM (Mean±SE; NH=2.35±0.11%, AL=2.39±0.15%).

Table 3.3. Change in body mass data (Mean±SE).

	Pre (kg)	Post (kg)	Change (kg)	Change (%)
NH	68.6±1.9	67.0±1.9	-1.6±0.2†	-2.4±0.4‡
AL	68.5±2.0	67.9±2.0	-0.6±0.5	-0.9±0.8

†=Significant change pre to post.
‡=Significantly different from AL trial.

Percent Change in Plasma Volume

There was no significant difference between trials for %ΔPV ($p=0.11$). However, there were two participants whose %ΔPV appeared to be artifacts. Specifically, one was the only subject to have a %ΔPV expansion greater than 6% (9.87%) during the NH trial. The other was the only subject to have a %ΔPV loss of more than 1% during the AL trial (-9.52%). After removing these data, there was a significant difference ($p<0.05$) between trials for %ΔPV (Mean±SE; NH=-2.93±2.42%, AL=+8.76±3.24%)

Exercising Heart Rate

Due to a malfunction with a heart rate monitor during one of the subject's RC trials, HR_{peak} was only available for the first five RC intervals. This data point was predicted using a linear regression and the subject's data during that RC trial. The equation from the linear regression was:

$HR_{peak} = 145.6 + (4.4 \text{ x Interval})$

Standard error for the intercept and slope were 5.11 and 1.54, respectively; $R^2=0.73$.

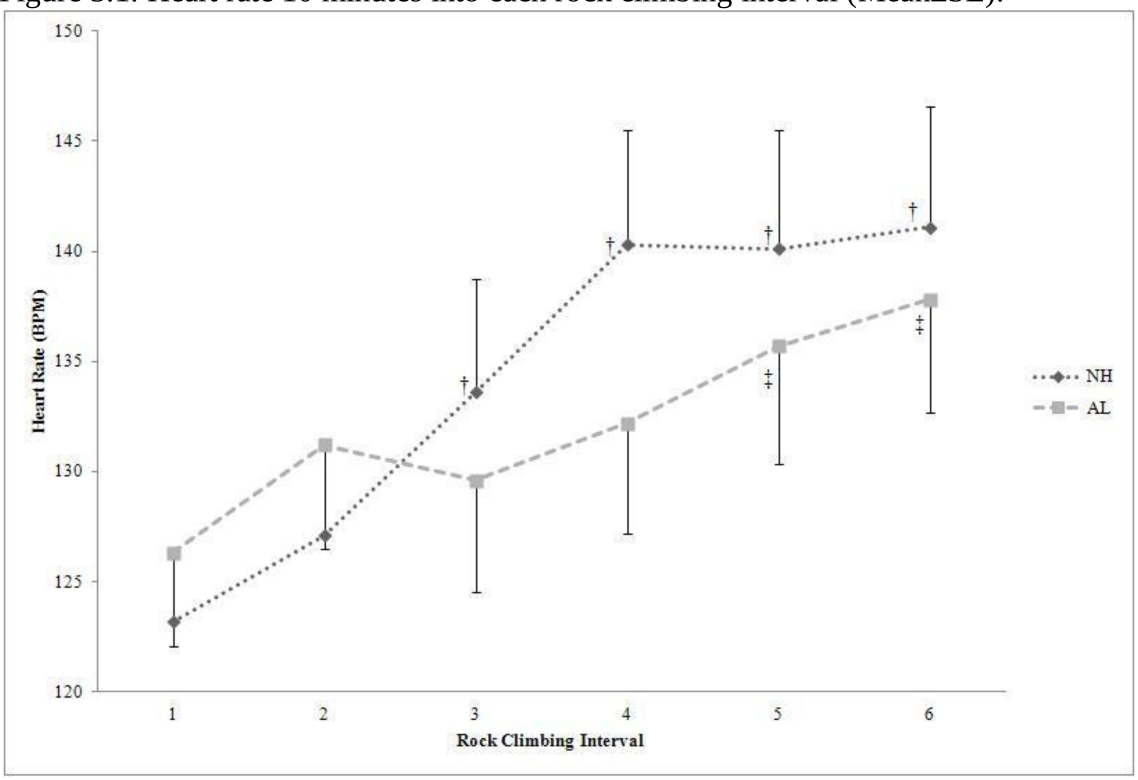
There was a significant increase in HR_{10min} ($p<0.05$) and HR_{peak} ($p<0.05$) during both trials, in addition, there was a significant interaction between time and trial for both

HR_{10min} ($p<0.05$) and HR_{peak} ($p=0.05$), but no significant differences for any of the intervals between trials (see Figures 3.1 and 3.2).

Rating of Perceived Exertion

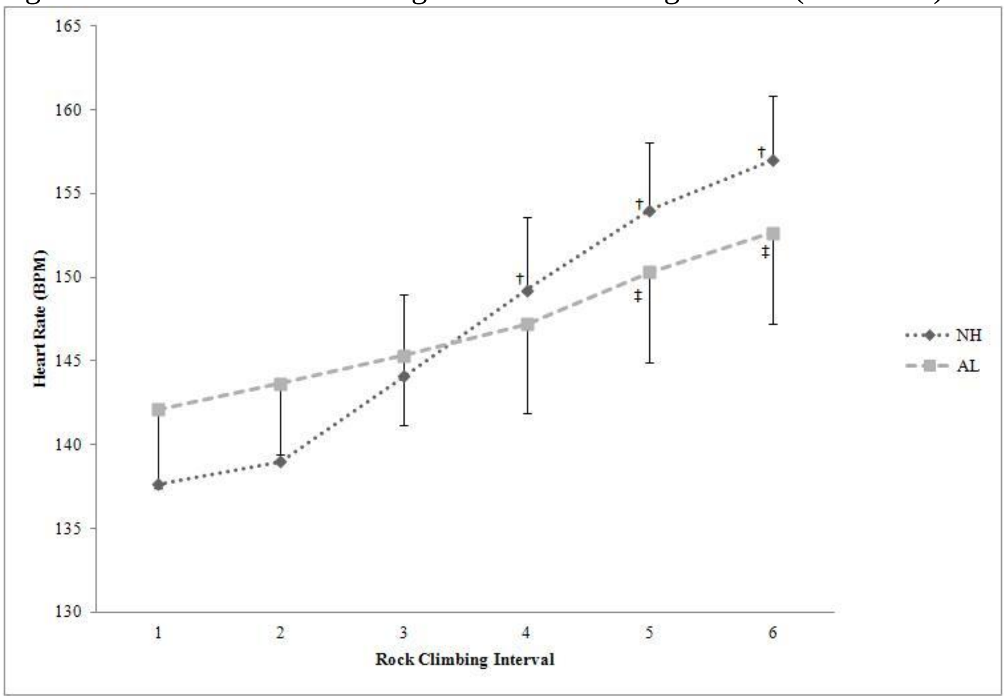
Rating of perceived exertion increased significantly ($p<0.05$) during both trials. However, there was not a significant interaction between trials or any differences for any of the intervals between trials (Figure 3.3).

Figure 3.1. Heart rate 10 minutes into each rock climbing interval (Mean±SE).



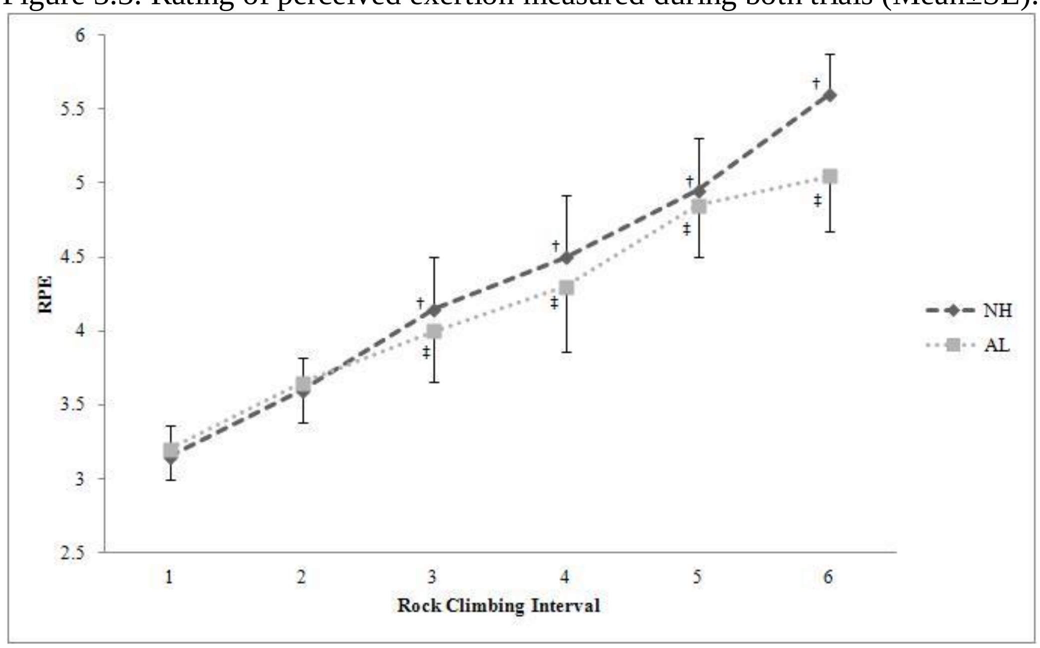
†: Significantly different from interval 1 during the non-hydration (NH) trial.
‡: Significantly different from interval 1 during the *ad libitum* (AL) trial.

Figure 3.2. Peak heart rate during each rock climbing interval (Mean±SE).



†=Significantly different from interval 1 during the non-hydration (NH) trial.
‡=Significantly different from interval 1 during the *ad libitum* (AL) trial.

Figure 3.3. Rating of perceived exertion measured during both trials (Mean±SE).



RPE = Rating of Perceived Exertion
†=Significantly different from interval 1 during the non-hydration (NH) trial.
‡=Significantly different from interval 1 during the *ad libitum* (AL) trial.

Urine Measures

Urine specific gravity did not significantly increase during either trial and there was not a significant difference between trials for ΔUSG (Table 3.4). Urine output was not significantly different between trials (NH=358.2±227.2 and AL=418.8±246.2 mL); but, there was a non-significant trend for UO to be higher during the AL trial (p=0.07).

Markers of Muscular Stress

Rhythmic isometric hand grip endurance decreased significantly during both trials; there was not a significant difference between trials for ΔRIHE (Table 3.4). Plasma CK did not increase significantly during either trial; ΔCK was not significantly different between trials (Table 3.4).

Table 3.4. Urine specific gravity, rhythmic hand grip endurance and plasma creatine kinase data for this study (Mean±SE).

	USG ($g \cdot mL^{-1}$)	**RIHE***	**CK (IU/L)**
Pre NH	1.007±0.001	33±8	141.2±81.7
Post NH	1.011±0.002	12±5	188.4±92.7
ΔNH	0.004±0.001	-20±9†	47.2±60.5
Pre AL	1.007±0.001	27±7	147.2±60.5
Post AL	1.012±0.010	11±4	183.2±80.3
ΔAL	0.005±0.004	-17±8†	42.6±56.1

NH=non-hydration trial, AL=*ad libitum* trial, USG=urine specific gravity, RIHE=rhythmic isometric hand grip endurance, CK=plasma creatine kinase
*=The number of 60-70% of MVIC hand grips.
†=Significant difference pre to post.

Discussion

The primary purpose of this study was to determine whether significant dehydration occurs during a 2-hour RC trial. The secondary purpose was to determine whether *ad libitum* water ingestion significantly reduces the amount of physiological stress induced by this dehydration. In turn, the significant findings of this study were: (1) According to %ΔBM and %ΔPV data, dehydration can take place during a 2-hour RC trial; (2) *Ad libitum* water ingestion delayed the onset of the cardiovascular stress commonly associated with dehydration; (3) There were no significant differences between trials for RPE, ΔCK, RIHE.

This is the first study to describe the amount of dehydration that can take place during simulated RC; according to %ΔBM dehydration did take place. The observed level of %ΔBM (2.4%) during simulated RC was similar to that reported during other athletic competitions and training (Sawka 2007; Noakes 1993). For example, a 2.4% loss in body mass would take place in ≈2 hours when using an approximate sweat rate for a 70 kg person running 10 $km \cdot h^{-1}$ (Montain, Cheuvront and Sawka 2006). This is helpful because Bourrilhon et al. (2009) reported an energy expenditure of 12.9 $kcal \cdot min^{-1}$ during the climbing section of an ultra endurance climbing race. Using the American College of Sports Medicine's running equation, this energy expenditure equates to a 70 kg person running ≈10 $km \cdot h^{-1}$ (Thompson, Gordon and Pescatello 2010). Thus the intermittent activity during RC will cause approximately the same amount of sweat loss as running ≈10 $km \cdot h^{-1}$. However, it is important to note that even though the subjects had significant dehydration according to %ΔBM, USG did not rise significantly during either trial or rise above the level (1.02 g·mL^{-1}) considered to be dehydrated (Sawka 2007). This may be explained by the fact that the subjects came into the lab more than adequately hydrated (if not hyperhydrated) with a mean USG of 1.007 for both trials.

A significant decrease in plasma volume (PV), approximately 3%, occurred due to the dehydration observed during this study. Others have reported losses in PV during dehydrating exercise; specifically Hamilton et al. (1991) reported a loss of 2 and 9% after 2-hours of cycling with no fluid replacement (NR) and with fluid replacement (FR). Hamilton et al. (1991) also reported that with this decrease in PV, there was a 7% and 15% decline in stroke volume (SV) and cardiac output (CO) during the NF trial and no change in SV and 7% increase in CO during the FR trial. Although the %ΔPV reported by Hamilton et al. (1991) was substantially different from the findings of the present study (a 9% loss compared to 3% loss) both had a %ΔBM greater than 2%, which led to an increased amount of cardiovascular stress.

Although a dehydration of 2% is far from a medical emergency, it is commonly accepted that this small amount of loss in body mass leads to increases in measured physiological stress and decreases in exercise performance (Sawka, 2007). In the present study, there was an observed increase in cardiovascular stress during both trials, as demonstrated by the significant time main affect, where HR increased by more than 10 BPM from start to finish. This phenomenon is commonly referred to as cardiac drift, as defined by Rowell (1974), and occurred during both trials. Specifically, HR_{10min} increased by 18 BPM (15%) and HR_{peak} increased by 19 BPM (14%) during the NH trial, while HR_{10min} increased by 12 BPM (9%) and HR_{peak} increased by 11 BPM (7%) during

AL trial. Hamilton et al. also observed an increase in HR during dehydrating exercise; specifically, a 10% increase in HR during the NF trial and a 5% increase during the FR trial (1991). Thus both the present study and Hamilton et al. (1991) report an increase in heart rate with and without fluid ingestion. Hamilton et al. hypothesized that the increase in HR was a response to the 7% decrease in SV; the decrease in SV due to a decrease in overall blood volume (1991). Although CO and SV were not measured during the present study, this author assumes that the decrease in PV during the NH trial led to a decrease in SV and the body responded by increasing HR to meet CO needs.

The second purpose of this research was to determine whether *ad libitum* water ingestion would significantly decrease the amount of physiological stress experienced due to the dehydration sustained during simulated RC. According to HR, *ad libitum* water ingestion did decrease the amount of physiological stress. As already reported, HR_{10min} and HR_{peak} increased by 14 and 15% during the NH trial while only increasing by 7 and 9% during the AL trial. This difference is why there was a significant interaction between time and trial. Specifically, although HR was not significantly different between trials, HR increased at a higher rate during the NH trial than during the AL trial. This difference may be explained by the water intake; water intake during the AL trial was 1.07 L and the difference between trials ΔBM was 1kg. Since the fluid retention rate was approximately 54%, about 0.5 L of fluid was available for PV expansion, which must have taken place since there was an 8% expansion of PV during the AL trial. This expansion of PV possibly in turn kept SV from decreasing as quickly during the NH trial.

Thus, a higher HR was not needed to meet CO needs. However, the water intake did not have a significant treatment affect on the other variables of physiological stress.

An interesting aspect of this study is the lack of significant differences between trials for RPE, ΔCK and ΔRIHE test scores. As expected, and like others have found (Montain and Coyle 1992b), RPE increased with time. The lack of significant differences between trials may be explained by the fact that the subjects who completed the study were expert level climbers. Of the 20 individuals who tried to complete the first visit, 13 were able to move on to the second visit. Of that 13, 10 completed the two experimental trials while two had to resign due to injuries sustained during recreational activities and one could not finish the second visit. Those who were able to complete the study were at such a high level of skill and conditioning that both trials were physically taxing but not overly so (two subjects are coaches for the local sport RC team, one was an experienced endurance climber who had plans to climb a difficult route on El Capitan shortly after the study, and one has been RC for over 20 years). This could also be the reason why there was not a significant difference between the trials for ΔCK. Others have found that hydration does have a treatment effect on indirect markers of muscle damage, such as CK and myoglobin (Seifert et al. 2005). However, this was not observed in this study. Subsequently, the fact that the subjects were at such a high level of experience and conditioning that insignificant muscle damage occurred during the trials.

The lack of difference between trials for ΔRIHE test scores could be due to the fact that there was not a sufficient amount of dehydration for muscular endurance to decrease. It has been previously reported that a dehydration of 3-4% must occur before significant decreases in muscular endurance precipitate (Saltin 1964; Torranin et al. 1979). Saltin (1964) examined the affect dehydration had on maximal upper body cranking. A 37% decrease in time to fatigue was reported after the subjects lost 4% of their body mass from exercise and heat exposure. Even more applicable was Torranin et al.'s (1979) findings, who tested isometric hand grip endurance and isotonic arm and leg endurance before and after a sauna induced loss of 4% of body mass. In their study, they found that all measures of muscular endurance decreased by 30%. Hence, a dehydration of 2.4% was sufficient to manifest increased cardiovascular stress but was insufficient to cause decreases in muscular endurance.

An important final consideration is that it appears the rock climbers in this study limited their water intake; four of the subjects consumed less than a liter. This appears to be a common trait among many rock climbers, because some subjects made the comment, during personal communications, that they are only in the habit of carrying water during a multi-pitch route, which are routes that have multiple severe changes in incline. Thus rock climbers should use a beverage that will optimize fluid retention in order to preserve hydration status as long as possible. For example, sodium chloride containing beverages have been shown to have a positive effect on rehydration and fluid retention (Gonzalez-Alonso et al. 1992; Greenleaf et al. 1998; Maughan and Lieper 1995; Merson, Maughan and Shirreffs, 2008; Shirreffs et al., 1996). Maughan and Lieper (1995) reported that there is a progressive rise in fluid retention as fluid osmolality increases, 36% with a ≈100 $mosmol \cdot kg^{-1}$ and up to 74% for ≈300 $mosmol \cdot kg^{-1}$. More recently, Merson, Maughan and Shirreffs (2008) reported that urine output progressively decreased and net fluid balance and plasma volume progressively increased as sodium chloride concentration was increased in a recovery beverage. This is further supported by the findings of Lee et al. who reported that fluid retention after a 75 minute exercise session and 5 hour recovery period was significantly greater for a sports drink (≈42%, 338 mosmol·kg^{-}1) than both water (≈32%) and a placebo drink (≈35%, 25 mosmol·kg^{-1}).

It has also been demonstrated that caloric content has a positive effect on fluid retention. Osterberg et al. (2010) compared the retention rate of carbohydrate and electrolyte beverages with different carbohydrate concentrations (3, 6, and 12%) to a placebo with and without electrolytes after a 2-3% exercise induced dehydration. They reported fluid retention was higher for the placebo with electrolytes (72%) than the placebo without electrolytes (66%), and even higher rates for the carbohydrate beverages, 75, 75, and 82% for the 3, 6, an 12% carbohydrate beverages respectively. Similar results were found by Seifert, Harmon and DeClercq (2006) who compared the fluid retention of water to a 6% carbohydrate beverage and a 6% carbohydrate and 1.5% protein beverage. Retention after exercise induced dehydration was 53% for water, identical to that found in this study, 75% for the 6% carbohydrate beverage and 88% for the carbohydrate and protein beverage. Thus, it appears that an isotonic beverage (containing sodium chloride, carbohydrate, and even some protein) has positive effects on fluid retention during and after exercise.

In conclusion, rock climbers can sustain significant dehydration during RC, as measured by %ΔBM. As suggested by researchers, an *ad libitum* hydration strategy appears to be a good starting point for minimizing dehydration sustained during RC, because it provides sufficient hydration to lower the cardiovascular stress associated with dehydration. Since rock climbers appear to limit their fluid intake, the consumption of an isotonic sports drink is suggested.

CHAPTER FOUR

CONCLUSIONS

As an intermittent physical activity, rock climbing (RC) has been shown to have the energy expenditure equivalent to running 6 mph, and as such, dehydration is possible during an extended RC session. The findings of this study substantiate this hypothesis; dehydration did occur according to %ΔBM, but not USG. Even though the level of dehydration achieved during the NH trial was similar to that reported by others who reported decreases in exercise capacity, there were no decreases in muscular endurance or differences in RPE. This may have been due to a combination of factors such as: the subjects' high level of experience and training status; the RC trials themselves were not stressful enough to cause significant muscle damage; due to temperate conditions, sweat loss was minimal in comparison to that which would have been achieved during an outdoor climbing session in a hot environment. However, there was an observed increase in cardiovascular stress.

Cardiac drift was manifest during both trials, but was more pronounced during the NH trial. This may have been due to a loss in plasma volume, owing to the water compartments changing as there was a loss of body water through sweat. Consequently, the water ingested during the AL trial helped preserve plasma volume, which may have limited the rate at which stroke volume decreased.

Finally, it appears that rock climbers limit their water intake due to the desire to limit the weight they carry, it is suggested that RC athletes hydrate with an isotonic beverage while RC. This is because researchers have found that when an isotonic beverage is consumed during and after exercise, fluid retention is increased. This increased fluid retention would hypothetically translate into a decreased level of dehydration.

Further research is suggested in order to have a complete description of the level of dehydration associated with RC. First, a study should focus solely on the dehydration of RC. For example, a study should collect venous blood samples before and after RC in order to have more precise methods in determining changes in blood volume and blood osmolality. Body mass should be collected more frequently and metabolic output measured in order to calculate a precise sweat rate during RC. Core temperature should also be measured. Finally, the study should be similar to the classic studies in dehydration, such as Adolph et al. (1947), having at least three trials, one without hydration, one with complete hydration, and one with *ad libitum* fluid intake. With all of this data, a complete picture of the amount of dehydration experienced during RC would be available to the scientific community.

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APPENDICES

APPENDIX A

SUBJECT CONSENT FORM

SUBJECT CONSENT FORM
FOR PARTICIPATION IN HUMAN RESEARCH
MONTANA STATE UNIVERSITY

PROJECT TITLE: *Physiological Stress of Experienced Rock Climbers Climbing on an Indoor Rock Climbing Treadmill*

PROJECT DIRECTOR: Brian Conder, Graduate Student, Exercise Physiology
Dept. of Health and Human Development, Movement Science Laboratory
H&PE Complex, Montana State University, Bozeman, MT 59717-3540
Office Phone: 994-5643; Lab Phone: 994-6314; E-mail: brian.conder@msu.montana.edu

FUNDING: This project is not funded by any commercial agency.

PURPOSE OF THE STUDY:
You are being asked to participate in a research study that will investigate the amount of physiological stress associated with rock climbing. If you decide to participate, you will be asked to make four separate visits to the Movement Science / Human Performance Laboratory (basement of Romney Building) over a 4 week period. The first two visits will last about 60 minutes while the third and fourth visits will last approximately 2.5 hours each.

This *Informed Consent Document* explains the purpose of the testing, as well as expected risks and benefits associated with participation. You will also be screened by the project director using your responses to a **Health History and Experience Questionnaire** (the Health History and Experience Questionnaires are attached to the end of this document). According to your responses to the Health History and Experience Questionnaire, if you are found to be of high risk of a catastrophic event, it is your responsibility to acquire medical clearance from your physician prior to lab testing. This procedure is in compliance with policies formulated by the American College of Sports Medicine[1].

Please talk with the Project Director, Brian Conder, about any pre-existing health conditions that may limit your participation in this project *BEFORE* testing, such as the following:

*Sickness (cold or flu)
*Injuries that could be aggravated by rock climbing
*You are a known or possible carrier of a blood born disease (e.g., hepatitis, HIV).

STUDY PROCEDURES:
Participation in this study is completely voluntary, and you may withdraw yourself from the study at any time. If you decide to participate, you will be asked to make four separate visits to the Movement Science / Human Performance Laboratory (basement of Romney Building). The first two visits will be the familiarization phase of the study; the purpose is to familiarize you with the rock climbing treadmill (RC_{tm}) that will be used during the study. Laboratory visits 3 and 4 are part of the data collection phase of the study, during which you will be asked to complete two 90 minute climbing bouts interspersed with 5 minute rest periods.

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[1] American College of Sports Medicine (2010). *ACSM's Guidelines for Exercise Testing and Prescription* (8th edition). Lea & Fibiger; Philedelphia, PA.

If you use an inhaler to treat asthma, be certain to bring the inhaler with you to the lab for every visit. You should arrive at the lab ready to engage in indoor rock climbing exercise which means to bring appropriate clothing. You do not need to bring a harness, ropes, or other protective equipment, just rock climbing apparel and shoes. You should also eat and drink fluids appropriate for the occasion (more detailed description for this is given below). *Again, if you use an inhaler to treat asthma, be certain to bring the inhaler with you to the lab.*

Lab Visits #1 and #2: Familiarization Visits

During familiarization visit one, first your height and weight will be recorded. Next, you will rock climb on the RC_{tm} at various speeds and inclination. The final task during this visit will be a maximal voluntary isometric contraction (MVIC) test. Specifically you will grip a hand dynamometer maximally, trying to attain the highest value possible. After which, you will rest for one minute and repeat the test two more times.

During familiarization visit two you will first warm up on the RC_{tm} for five minutes. After the warm up you will climb on the RC_{tm} for 45 minutes, the 45 minutes being separated into three 15 minute bouts with a 5 minute rest between bouts. The rock climbing bouts will consist of the same protocol that will be used during the data collection phase. The final task during this visit will be a rhythmic isometric hand grip strength test. The protocol will consist of you gripping at 50 to 60 percent of your previously determined hand grip MVIC for three seconds and then rest for three seconds. This will be repeated until you can no longer hold a 50 to 60 percent MVIC for three seconds.

Lab Visits #3 and #4: Data Collection Visits

For the 24 hours previous to the experimental trials you will be asked to abstain from alcohol consumption and strenuous exercise of any kind. You will also be asked to abstain from caffeine consumption the day of both experimental trials, and to consume a meal at least three hours previous to both visits. You will also be asked to consume 16 ounces of water one hour previous to the lab visits 3 and 4.

As stated earlier during the experimental trials, you will engage in 90 minutes of climbing. Specifically, you will complete six 15 minute intervals with an estimated Yosemite Decimal System rating of 5.11. There will be a 5 minute rest period after each interval. The goal of this exercise bout is to measure the amount of physiological stress associated with rock climbing.

During both of the experimental trials you will need to bring *your own rock climbing shoes* to the Movement Science Laboratory for the climbing exercise. Prior to the start of climbing, you will provide a urine sample that will be analyzed to insure you are adequately hydrated. If you are found to be mildly dehydrated you will be asked to drink 16 ounces of water and another urine sample will be collected after 45 minutes, which will also be analyzed. If you are found to be substantially dehydrated you will be asked to schedule a new lab visit. If you are adequately hydrated you will be weighed nude while standing on a scale inside a private room and an investigator on the other side of the door records weight from a digital readout on an extension cord. Next, you will sit in a chair for 15 minutes, after which a finger prick blood sample, similar to what diabetics use to determine blood glucose levels, will be collected in order to determine your plasma creatine kinase, hemoglobin, and hematocrit levels. The final test before your climbing session will be a rhythmic isometric hand grip strength (RIHS) test, which consists of you gripping at 50 to 60 percent of your MVIC for three seconds and then rest for three seconds. This will be repeated until you can no longer hold a contraction that is 50 to 60 percent of your MVIC. After which you will be fitted with a chest strap heart rate monitor and wrist receiver.

You will next warm up on the RC_{tm} for five minutes at a speed of 4.5 $m \cdot min^{-1}$ at a positive 5° grade. After the warm up you will step off the RC_{tm} and the RC_{tm} will be prepared for the rock climbing session. When the RC_{tm} has been prepared you will step onto the RC_{tm} and the climbing session will begin. Table 1. describes the rock climbing route that will be used.

Table 1. Rock Climbing protocol.

Stages	Duration (min)	Total Climbing Time (min)	Degrees from vertical	Speed(m/min)	Vertical Distance Climbed (m)
1	1	1	0	7.5	7.5
2	1	2	-10	4.5	12
3	1	3	-20	4.5	16.5
4	.5	3.5	-30	3.5	18.25
5	.5	4	+5	3.5	20
6	1	5	+5	8.0	28
7	2	7	0	7.5	43
8	2	9	-5	4.5	52
9	.5	9.5	+10	5.5	54.75
10	.5	10	+10	7.5	58.5
11	1	11	-40	3.5	62
12	1	12	+5	3.5	65.5
13	1	13	0	6	71.5
14	2	15	-5	4.5	80.5

After completing the first climbing interval you will step off the RC_{tm} and will be asked to sit down and rest for 5 minutes. At the beginning of the rest period you will be asked to rate the amount of effort on a scale of 0 to 10, 0 meaning absolutely no effort and 10 meaning your maximal effort, you feel you had to exert during the 15 minute climbing interval, commonly referred to as RPE. This pattern will then be repeated until you have completed 90 minutes of climbing. Lab visits 3 and 4 will be identical, except during one you will receive water during the five minute breaks.

After 90 minutes of climbing has elapsed you will be asked to sit for 15 minutes, after which a finger prick blood sample will be collected for hemoglobin and hematocrit analysis. After this you will be asked to once again be weighed nude while standing on a scale inside a private room while an investigator on the other side of the door records weight from a digital readout on an extension cord. You will then be asked to provide a urine sample for urine specific gravity and urine volume measurement, which will be collected by you in the buildings rest room. Finally, you will be asked to return to the lab within 24 hours to provide a finger prick blood sample.

POTENTIAL RISKS: There are potential risks associated all of the lab visits.

Bouts of Climbing on the RC_{tm}: It is likely that all of the climbing sessions may cause some muscular fatigue immediately afterwards and possibly during the next day. Dehydration is also possible during the two 90 minute climbing sessions. Falling off the treadmill is possible; however, there is a mat directly below the RC_{tm}. Further, it is possible that any high intensity exercise, such as the rock climbing, can cause injury or even death. However, the possibility of such an occurrence is very slight (less than 1 in 10,000) since 1) you are in good physical condition with no known symptoms of heart disease and 2) the sessions will be administered by trained personnel (American Red Cross CPR certified and aware of the lab's emergency action plan). *These risks are certainly no greater than those experienced by trained athletes in actual rock climbing situations.* The measuring devices (heart rate monitor chest strap) may feel somewhat restricting and/or uncomfortable during testing, but all possible adjustments will be used to achieve your comfort.

Blood Collection:
Approximately 5 drops of blood will be removed by finger stick. This is a standard method used to obtain blood for routine hospital laboratory tests. You will experience pain when the lancet goes into your finger. Other than this momentary pain, the discomfort of finger stick should be minimal. However, in about 10% of the cases a small amount of bleeding under the skin will produce a bruise (hematoma). A small scar may persist for several weeks. The risk of local infection is less than 1 in 1,000. Universal safety precautions will be used in the handling of blood samples.

BENEFITS:
Subjects will learn about their personal physiological responses to 90 minutes of climbing. Study participants may also request a summary of the study findings by contacting the Project Director, Brian Conder, by phone (994-5643) or by e-mail (brian.conder@msu.montana.edu).

COMPENSATION:
No monetary compensation is being provided in this study.

CONFIDENTIALITY:
The data and personal information obtained from this study will be regarded as privileged and confidential. Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. Your right to privacy will be maintained in any ensuing analysis and/or presentation of the data by using coded identifications of each person's data. The code list will be kept separate and secure from the actual data files. All records and data will also be stored in a locked container; electronic data will be stored in a locked data file and lockable computer.

PROOF OF HEALTH INSURANCE:
Proof of health insurance must be provided to the principle investigator, in order to insure that you have health care available to them if they become sick or injured due to the study.

FREEDOM OF CONSENT:
Participation in this project is completely voluntary. You may withdraw consent for participation in writing, by telephone, or in person without prejudice or loss of benefits (as described above). Please contact the Project Director, Brian Conder, by phone (994-5643) or by e-mail (brian.conder@msu.montana.edu) to discontinue participation.

In the UNLIKELY event that your participation in the project results in physical injury to you, the Project Director will advise and assist you in receiving medical treatment. However, no funds are available from the project or Montana State University to cover the costs of such treatment. You are encouraged to express any questions, doubts or concerns regarding this project. The Project Director will attempt to answer all questions to the best of their ability prior to any testing. The Project Director fully intends to conduct the study with your best interest, safety and comfort in mind. *Additional questions about the rights of human subjects can be answered by the Chairman of the Human Subjects Committee, Mark Quinn, at 406-994-5721.*

PROJECT TITLE: ***Physiological Stress of Experienced Rock Climbers Climbing on an Indoor Rock Climbing Treadmill***

STATEMENT OF AUTHORIZATION

I, *the participant*, have read the Informed Consent Document and understand the discomforts, inconvenience, risks, and benefits of this project. I,____________________ *(print your name)*, agree to participate in the project described in the preceding pages. I understand that I may later refuse to participate, and that I may withdraw from the study at any time. I have received a copy of this consent form for my own records.

Signed:____________________________ **Age**_______
Subject's Signature **Date**______

Witness: ________________________
Print Name

Sign Name:______________________

APPENDIX B

HEALTH HISTORY AND ROCK

CLIMBING EXPERIENCE QUESTIONNAIRE

Health History Questionnaire (HHQ) - Montana State University
Movement Science / Human Performance Laboratory

INSTRUCTIONS

Complete each of the following questions as accurately as possible by filling in the blanks or checking the most appropriate box. All information provided is confidential and no information will be released without your written consent.

*Today's Date*______________

GENERAL INFORMATION

Mr. ❍ *Ms.* ❍ *Miss* ❍*Mrs.* ❍ *Dr.* ❍

Last Name _____________________________ *First Name* _____________________

Mailing Address ____

____

Home Phone _________________________ *Office Phone* ______________________

Occupation ____

Employer ____

Person to Contact in Emergency: *Name* ___________________________________

Relationship ______________________________

Phone ________________________________

▪ *Descriptive information:*

Gender: *Male* ❍ *Female* ❍ *Body Weight* ____________

Age _______ *Date of Birth* ___________ *Body Height* _____________

▪ *Why are you filling out this questionnaire?*

❍ *You have volunteered for a research study or project.*

❍ *You are being screened for fitness testing in the Movement Science Lab.*

❍ *Other reason...*____

MEDICAL HISTORY

*Name of your physician*________________________________

*(Address/phone?)*________________________________

▪ *Family History:*

Did your father, or other first degree male relative (like a brother) die before the age of 55?

No ❍ *Yes* ❍ *If Yes, cause?* _____________________

Age at death? _____________________

*Which relative?*_____________________

Did your mother, or other first degree female relative (like a sister) die before the age of 65?

No ❍ *Yes* ❍ *If Yes, cause?* _____________________

Age at death? _____________________

Which relative? _____________________

▪ *List any food or drug allergies:* _________________________________

____

____

____

▪ *List any medication you are currently taking (non-prescription and prescription, including oral contraceptives). Please comment on the reason for each medication.*

____

____

____

____

____

____

▪ *Please describe any recent illnesses, hospitalizations, or surgical procedures:*

____

____

____

____

____

▪ *Any of these health symptoms that occurs frequently (ranked as either a 4 or 5 below), <u>either at rest or during physical exertion</u>, is the basis for a prompt medical evaluation. Circle the number indicating how often you have each of the following:*

0 *= Never* ***1*** *= Practically never* ***2*** *= Infrequently*

3 *= Sometimes* ***4*** *= Fairly often* ***5*** *= Very often*

a. Coughing up blood.	*0*	*1*	*2*	*3*	*4*	*5*
b. Abdominal pain.	*0*	*1*	*2*	*3*	*4*	*5*
c. Low-back pain.	*0*	*1*	*2*	*3*	*4*	*5*
d. Chest pain.	*0*	*1*	*2*	*3*	*4*	*5*
e. Neck, jaw, arm, or shoulder pain.	*0*	*1*	*2*	*3*	*4*	*5*
f. Leg pain.	*0*	*1*	*2*	*3*	*4*	*5*
g. Swollen joints, especially the ankles.	*0*	*1*	*2*	*3*	*4*	*5*
h. Feel faint.	*0*	*1*	*2*	*3*	*4*	*5*
i. Feeling of dizziness.	*0*	*1*	*2*	*3*	*4*	*5*
j. Breathless with slight exertion.	*0*	*1*	*2*	*3*	*4*	*5*
k. Palpitation or fast heart rate.	*0*	*1*	*2*	*3*	*4*	*5*
l. Unusual fatigue with normal activity.	*0*	*1*	*2*	*3*	*4*	*5*
m. Abnormal/labored breathing at night.	*0*	*1*	*2*	*3*	*4*	*5*

For any score of "4" or higher, use the space below to explain the frequency and the conditions under which you experience that particular symptom:

____

____

____

____

____

____

____

· *Please indicate which of the following for which* ***you have been diagnosed or treated*** *by a physician or health professional. Please be as complete as possible.*

Check if "Yes" *If "Yes", please comment further...*

❍ *Alcoholism* ____________________
❍ *Anemia, sickle cell* ____________________
❍ *Anemia, other* ____________________
❍ *Asthma* ____________________
❍ *Back strain* ____________________
❍ *Blood pressure -* *High?* ____________________
Low? ____________________
❍ *Bronchitis* ____________________
❍ *Cancer* ____________________
❍ *Cirrhosis, liver* ____________________
❍ *Cholesterol -* *High?* ____________________
❍ *Concussion* ____________________
❍ *Congenital defect* ____________________
❍ *Diabetes* *Type?*____________________
❍ *Emphysema* ____________________
❍ *Epilepsy* ____________________
❍ *Eye problems* ____________________
❍ *Gout* ____________________
❍ *Hearing loss* ____________________
❍ *Heart problems* ____________________
❍ *Hypoglycemia* ____________________
❍ *Hyperlipidemia* ____________________
❍ *Infectious mononucleosis* ____________________
❍ *Kidney problems* ____________________
❍ *Menstrual irregularities* ____________________
❍ *Mental illness* ____________________
❍ *Neck stain* ____________________
❍ *Obesity* ____________________
❍ *Phlebitis* ____________________
❍ *Rheumatoid arthritis*____________________
❍ *Stroke* ____________________

❍ *Thyroid problems* ______________________________

❍ *Ulcer* ______________________________

❍ *Other* ______________________________

____

____

BLOOD CHEMISTRY PROFILE

▪ *Have you ever had a fasting blood sample analyzed for cholesterol?* ❍ *Yes* ❍ *No*

If "Yes", when was last time your blood was analyzed? ____________________

If "Yes", please provide as much detail as possible with regard to the specific blood components requested below (most recent test results only). Ideally, we would like both the numerical value of the test result AND the units of the measurement (the units are typically reported along with the numerical value of the test result).

· *Total serum cholesterol* __________ *units?* __________

· *HDL (high density lipoprotein)* __________ *units?* __________

· *LDL (low density lipoprotein)* __________ *units?* __________

· *VLDL (very low density lipoprotein)* __________ *units?* __________

· *Triglycerides* __________ *units?* __________

· *Blood glucose* __________ *units?* __________

· *Hemoglobin* __________ *units?* __________

· *Hematocrit* __________ *units?* __________

· *Iron* __________ *units?* __________

HEALTH-RELATED BEHAVIORS

▪ *Do you now smoke?* ❍ *Yes* ❍ *Infrequently* ❍ *No*

If "Yes" or "Infrequently", indicate the number smoked per day (on average):

Cigarettes: *40 or more* *20-39* *10-19* *1-9*

*Cigars/pipes - describe:*____

▪ *Have you recently quit smoking?* ❍ *Yes* ❍ *No*

If "Yes", how long ago did you quit? ________ *years* _________ *months*

▪ *Do you currently work in an environment where smoking is allowed?*

❍ *Yes* ❍ *No*

If "Yes", where do you work AND how frequently do you work in this environment?

▪ *Do you drink alcoholic beverages on a regular basis?* ❍ *Yes* ❍ *No*
(ie. at least once/week)

If "Yes", please answer the following:
1) How frequently do you drink?

2) What alcoholic beverages do you typically consume?

▪ *Have you* ***exercised*** *regularly in the past 4 weeks?* ❍ *Yes* ❍ *No*
If "Yes", describe in terms of frequency, duration, intensity, and type of exercise:

▪ *Do you consider yourself* ***physically active*** *due to work-related demands, home or farm chores, etc.?* ❍ *Yes* ❍ *No*
If "Yes", describe in terms of frequency, duration, intensity, and type of exercise:

▪ *Please describe anything not already described on this questionnaire that might cause you problems during exercise (use the space below).*

▪ *Are there any other health-related problems or concerns NOT addressed on this questionnaire that we should know about?* ❍ *Yes* ❍ *No*
If "Yes", please describe:

Experience Questionnaire

The purpose of this questionnaire is to establish your level of rock climbing experience.

- How many years of rock climbing experience do you have? ___________
- Have you been actively climbing for the last two years? _______________
- What is the most difficult indoor route you have successfully finished (following the YDS scale)? ______________
- What is the most difficult outdoor route you have successfully finished (following the YDS scale)? ___________

APPENDIX C

ROCK CLIMBING RATING SYSTEM COMPARISON

UIAA	French	YDS	Australian	Brazilian
I	1	5.2		
II	2	5.3	11	
III	3	5.4	12	II
IV	4	5.5	12 13	II IIsup
V-	5	5.6 5.7	13	IIsup III IIIsup
V	5	5.7	14	IIIsup
V+	5	5.7 5.8	15	IIIsup IV
VI-	5	5.8	16 17	IV
VI	5 6a	5.8 5.9	17 18	IVsup V
VI+	6a 6a+	5.9 5.10a	18 19	V
VII-	6a+ 6b	5.10a 5.10b 5.10c	19 20 21	V Vsup
VII	6b+ 6c	5.10c 5.10d	21 22	VI VIsup
VII+	6c 6c+	5.11a 5.11b	22 23	VIsup VII
VIII-	6c+ 7a	5.11b 5.11c	23 24	VII VIIsup
VIII	7a+ 7b	5.11d 5.12a	25	VIIsup VIII
VIII+	7b 7b+	5.12a 5.12b	25 26	VIII VIIIsup
IX-	7b+ 7c	5.12b 5.12c 5.12d	26 27	VIIIsup
IX	7c 7c+	5.12d 5.13a	27 28	
IX+	8a 8a+	5.13a 5.13b	29 30	
X-	8a+ 8b	5.13c 5.13d	30 31	
X	8b 8b+	5.13d	31 32	
X+	8b+ 8c	5.13d 5.14a 5.14b	32 33	
XI-	8c 8c+	5.14b 5.14c	33	
XI	9a	5.14c 5.14d	33	
XI+	9a+	5.14d 5.15a	33	
XII-	9a+	5.15b	33	

This Table was adapted from Eng R & Van Pelt J. Mountaineering: The Freedom of The Hills. 8 ed. Seattle: The Mountaineers Books; pg 565; 2010
UIAA: Union Internationale Des Associations D’Alpinisme (International Mountaineering and Climbing Federation)
YDS: Yosemite Decimal System