Effect of oral creatine supplementation on upper extremity anaerobic response in females
by Karyn Hamilton Ward

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Health and Human Development
Montana State University

Abstract:
Most oral creatine monohydrate (CrH2O) research has been focused on lower body strength and power in males. The purpose of this study was to investigate the influence of standard doses of oral CrH2O on muscular performance during elbow flexion (EF) and shoulder internal rotation (IR) in females. Following written informed consent, 24 females involved in overhand sports were pair-matched on lean body mass, % body fat, height, weight (Wt), and age, and assigned to either placebo (P) (n=13) or CrH2O (n=11) groups in a randomized, double-blind fashion. Peak concentric (CON) and eccentric (ECC) isokinetic (IK) torque, isotonic (IT) one repetition maximum (1RM), and muscular fatigue (FAT) during EF, and IT 1RM, FAT, and peak velocity (V) during IR were evaluated. Following habituation, subjects consumed either P or 25 g CrH2O/day for a seven day dietary phase. All subjects were weighed and tested before and after the dietary phase. Repeated measures MANOVAs revealed a significant interaction between treatment and trial for EF (F 419=5.30, p=0.005) but not for IR (F319=0.06, p=0.98) or Wt (F123=0.66, p=0.43). Post hoc univariate analysis indi-cated a significantly (p=0.006) greater change in EF Fat following CrH2O than following P. Results suggest oral CrH2O did not influence peak EF or IR strength, IR work to fatigue, or peak IR velocity in strength-trained, female athletes. Therefore, CrH2O supplementation may be of benefit for enhancing strength conditioning but not performance of overhand sports.

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APPROVAL

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Karyn Hamilton Ward

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Most oral creatine monohydrate (CrH_2O) research has been focused on lower body strength and power in males. The purpose of this study was to investigate the influence of standard doses of oral CrH_2O on muscular performance during elbow flexion (EF) and shoulder internal rotation (IR) in females. Following written informed consent, 24 females involved in overhand sports were pair-matched on lean body mass, % body fat, height, weight (Wt), and age, and assigned to either placebo (P) (n=13) or CrH_2O (n=11) groups in a randomized, double-blind fashion. Peak concentric (CON) and eccentric (ECC) isokinetic (IK) torque, isotonic (IT) one repetition maximum (1RM), and muscular fatigue (FAT) during EF, and IT 1RM, FAT, and peak velocity (V) during IR were evaluated. Following habituation, subjects consumed either P or 25 g CrH_2O/day for a seven day dietary phase. All subjects were weighed and tested before and after the dietary phase. Repeated measures MANOVAs revealed a significant interaction between treatment and trial for EF ($F_{4,19}$=5.30, p=0.005) but not for IR ($F_{3,19}$=0.06, p=0.98) or Wt ($F_{1,23}$=0.66, p=0.43). Post hoc univariate analysis indi-cated a significantly (p=0.006) greater change in EF_{FAT} following CrH_2O than following P. Results suggest oral CrH_2O did not influence peak EF or IR strength, IR work to fatigue, or peak IR velocity in strength-trained, female athletes. Therefore, CrH_2O supplementation may be of benefit for enhancing strength conditioning but not performance of overhand sports.

CHAPTER I

INTRODUCTION

The use of an ergogenic substance refers to the application of a pharmacological, nutritional, physiological, psychological, or mechanical aid which is perceived to enhance athletic performance by improving strength, speed, endurance, or recovery of an athlete (McArdle, Katch, & Katch, 1991). Ergogenic aids may exert their effects by directly acting on muscle tissue, supplying fuel necessary for muscle contraction, or minimizing effects of metabolic by-products. Enhancing cardiovascular and circulatory response and stimulating the central nervous system are two additional routes through which ergogenics may act (Berglund & Hemmingsson, 1982; Chandler & Blair, 1980; Fox, Bowers, & Foss, 1993).

Enhancement of athletic performance with the use of ergogenic aids is a topic of international controversy. The use of anabolic steroids, amphetamines, and blood doping, for example, is prohibited by national and international sports medicine groups and governing bodies including the American College of Sports Medicine, the International Olympic Committee, the United States Olympic Committee, and the American Medical Association (American College of Sports Medicine, 1987a; American College of Sports Medicine, 1987b; United States Olympic Committee, 1989). However, the application of other ergogenics, such as training, dietary manipulation, nutritional supplements, and high performance equipment, is deemed acceptable at this time.

Athletes striving for a "competitive edge" constitute a vulnerable population typically targeted for ergogenic sales (Karpovich, 1971; McArdle et al., 1991). With a growing number of people participating in recreational and amateur sports, production and sales of ergogenic aids has become a lucrative industry with a steady increase in the number and variety of new

products marketed annually. One such product is creatine monohydrate (CrH_2O). When taken orally during training, CrH_2O is purported to enhance fuel supply for working muscles, ultimately resulting in improved strength, endurance, and fat-free mass (Balsom, Ekblom, Soderlund, Sjodin, & Hultman, 1993a; Bleue & Goodman, 1995; Greenhaff et al., 1993b; Lemon et al., 1995).

The majority of research conducted on the efficacy of CrH_2O, though somewhat equivocal, includes compelling findings with regard to improved lower extremity strength and anaerobic capacity primarily in males of varying fitness classifications (Balsom et al., 1993a; Bleue & Goodman, 1995; Greenhaff et al., 1993b; Lemon et al., 1995). However, information on the effects of CrH_2O on upper body strength and anaerobic power is limited. In addition, since the majority of research has included primarily male subjects, little is known concerning the physiological response of females following CrH_2O supplementation. Therefore, the purpose of this study was to quantify the effects of CrH_2O supplementation on the upper extremity anaerobic response of females. The results of this study should be of value to female athletes who are using or considering the use of oral creatine supplements for the purpose of enhancing upper body strength. Exercise scientists, coaches, and athletic trainers should also benefit through a greater knowledge of nutritional supplementation when counseling athletes.

Statement of the Problem

The purpose of this study was to quantify the effects of oral creatine monohydrate on upper extremity isokinetic and isotonic strength and velocity in females.

Research Objectives

The investigation attempted to fulfill the following objectives:

1. Quantify the efficacy of oral creatine supplementation on upper extremity isotonic peak torque and velocity in females.

2. Quantify the efficacy of oral creatine supplementation on upper extremity isokinetic peak torque in females.

Hypotheses

The following null hypotheses were tested:

1. Oral creatine supplementation will have no effect on upper extremity isotonic peak torque and velocity in females.
2. Oral creatine supplementation will have no effect on upper extremity isokinetic peak torque in females.

Assumptions

1. Subjects were adequately informed and trained on all procedures and phases of the investigation to facilitate optimal completion of the study.
2. Subjects put forth maximal effort for optimal physiological response to achieve a maximal level of upper extremity strength, endurance, and biomechanical efficiency.

Limitations

1. Results were generalizable only to college-aged, strength-trained females participating in competitive or recreational overhand sports.
2. Results were derived within a laboratory setting rather than during performance in an actual sport-specific environment.

Delimitations

1. Inference was made only to college-aged, strength-trained females participating in overhand sports.
2. Subjects were tested using sport-specific movements to simulate a sport environment.

CHAPTER II

REVIEW OF THE LITERATURE

Anaerobic Energy Production

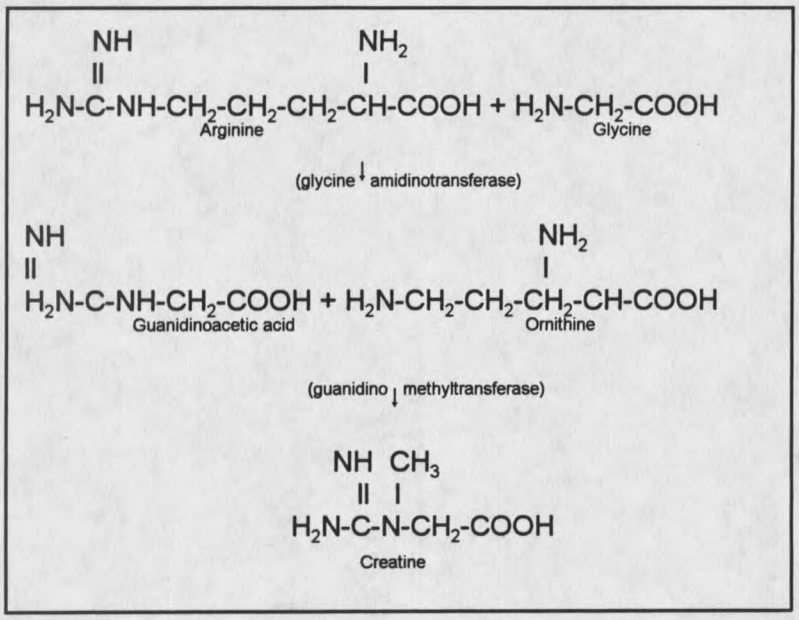
Muscular work is dependent on availability of energy derived from dephosphorylation of adenosine triphosphate (ATP) (diPrampero, 1976; Marechal, 1981; Rall, 1988). Work requiring efforts of maximal intensity, but of short duration, depends highly on anaerobic production of energy through only two processes: (1) the adenosine triphosphate-phosphocreatine (ATP-PC) system, and (2) glycolysis, i.e., the lactic acid system (diPrampero, 1976; Newsholme, 1981). The ATP-PC system is a metabolic process which provides immediate, high power, short-term energy for muscle contraction (Davies, 1965; Hultman, 1967; Karlsson, 1971). The lactic acid system provides energy for up to approximately two to three minutes resulting in lactate accumulation which can contribute to a decline in blood pH (diPrampero, 1976; Fox et al., 1993).

Phosphocreatine Availability, Storage, and Degradation

An understanding of the availability, storage, and breakdown of phosphocreatine (PC) is imperative for an appreciation of its physiological roles. Creatine (Cr), the unphosphorylated form of PC, is available both from dietary intake of meat and fish (which provide about 5 g Cr/kg or an estimated average daily Cr intake of 1 g/day) and via biosynthesis in the liver, pancreas, and kidneys from the non-essential amino acids arginine and glycine (see Figure 1; Balsom, Soderlund, & Ekblom, 1994; Devlin, 1982; Hoogwerf, Laine, & Greene, 1986; Lykken, Jacob, Munoz, & Sandstead, 1980; Walker, 1960). Biosynthesis, alone, appears to be capable of supplying adequate amounts of Cr in normal

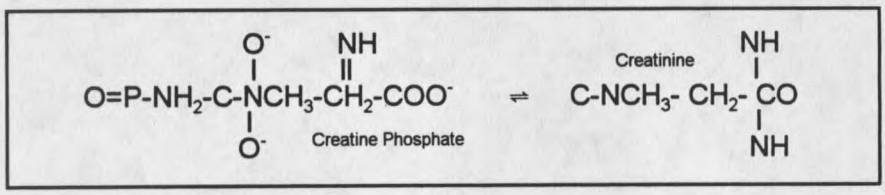
individuals as demonstrated by normal muscle Cr concentrations in vegetarian subjects (Harris, Soderlund, & Hultman, 1992). Regardless of its origin, Cr is transported by the blood

Figure 1. Biosynthesis of Cr From Arginine and Glycine



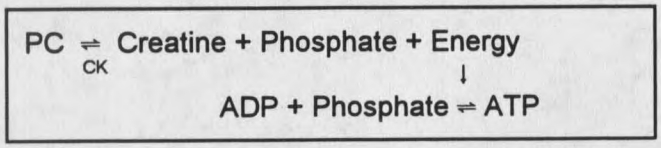
and either phosphorylated and stored directly in muscle cells, the fate of approximately 95% of Cr, or spontaneously converted to creatinine for excretion in the urine (approximately 2 g/day; see Figure 2) (Balsom et al., 1994; Delanghe et al., 1989; Hoberman, Sims, & Peters, 1948; Hunter, 1928; Zubay, 1988). Creatine gains entry into muscle cells via a sodium-dependent transporter (Guimbal & Kilimann, 1993). The body's total Cr pool is estimated to be approximately 120 g in a 70 kg human or approximately 124 mmol/kg dry muscle (Harris, Hultman, & Nordesjo, 1974; Walker, 1960).

Figure 2. Interconversion of PC and Creatinine



Phosphocreatine provides energy for muscular contraction via continual storage and degradation. Though ATP is the major energy source for muscular work, ATP storage in muscle is very limited with an estimated total energy availability of only 1.2-1.8 kcal/kg muscle used, assuming 10 kcal/mole of ATP and 30 kg of muscle in a 70 kg man (Hultman, 1967; Karlsson, 1971). Since the demand for ATP greatly exceeds its storage, working skeletal muscle must rely on other substrates for energy. As one of the first stored forms of high energy phosphate to be discovered, PC is an energy reservoir for the resynthesis of ATP (Fiske & Subbarow, 1929). Estimated PC availability is 4.5-5.1 kcal/kg muscle (Hultman, 1967; Karlsson, 1971; McArdle et al., 1991). When PC is dephosphorylated through enzymatic action of creatine kinase (CK), a large amount of energy is liberated and used to rephosphorylate adenosine diphosphate (ADP), a precursor to ATP (see Figure 3; Davies, 1965; McArdle et al., 1991).

Figure 3. Utilization of PC for Resynthesis of ATP



Buffering and Phosphocreatine

In addition to its role of rapidly regenerating ATP, PC may also play a role in shuttling energy and buffering environmental changes at sites of high energy utilization during muscle contraction (Davies, 1965; McArdle et al., 1991; Wallimann, Wyss, Brdiczka, Nicolay, & Eppenberger, 1992). Phosphocreatine and Cr are capable of "shuttling" high energy phosphates between the mitochondria and the myofibrils (Bessman & Geiger, 1981; Jacobus & Lehninger, 1973; Meyer, Sweeney, & Kushmerick, 1984; Savabi, Carpenter, Mohan, &

Bessman, 1988; Wallimann et al., 1992). The "PC shuttle" is a communicator and energy carrier between locations of high energy production and locations of high energy utilization. Three sites at which the PC shuttle operates have been proposed: (1) at the myosin heads during muscle contraction, (2) in the mitochondria, and (3) between these two areas of energy production and utilization (Bessman & Carpenter, 1985; Wallimann et al., 1992).

At sites of accelerated energy utilization near the contractile proteins, PC buffers changes in concentrations of ATP, ADP, and protons via CK (Figure 3). Low pH resulting from H^+ accumulation is thought to contribute to muscle fatigue via direct action on skeletal muscle contractile proteins and by disturbing the equilibrium of key enzymes such as myosin phosphofructokinase (PFK), phosphorylase, ATP-ase, and CK (Fabiato & Fabiato, 1978). Because regeneration of ATP from ADP involves acceptance of a proton (H^+), the CK reaction may help minimize H^+ accumulation, thus, delaying a decrease in pH and the subsequent onset of fatigue (Iyengar, 1984; Iyengar, Fluellen, & Iyengar, 1982; Wallimann et al., 1992). Following regeneration of ATP, the free Cr can then be transported back to the mitochondria, undergo rephosphorylation by CK, and be shuttled back to areas of high energy utilization (Bessman & Geiger, 1981; Jacobus & Lehninger, 1973; Meyer et al., 1984; Wallimann et al., 1992).

The role of PC may be important from the onset of high-intensity exercise through early recovery. Muscle PC concentration rapidly declines within the first two minutes of intense physical work as PC is utilized for ATP regeneration, and then stabilizes unless work loads exceed maximal capacity for steady state (Greenhaff, Soderlund, Ren, & Hultman, 1993c; Harris, et al., 1976; Hultman, Bergstrom, & McLennan-Anderson, 1967). The "PC shuttle" carries essential energy from locations of synthesis and storage to areas of intense muscle contraction (Bessman & Geiger, 1981; Jacobus & Lehninger, 1973; Meyer et al., 1984; Wallimann et al., 1992). PC's buffering functions may be particularly important during high-intensity exercise when anaerobic glycolysis predominates, and increases in lactic acid, H^+,

and fatigue are observed (Wallimann et al., 1992). With supramaximal workloads, muscle PC concentration can decrease rapidly to near zero with subsequent cessation of muscle contraction. Whether cessation of muscle contraction occurs voluntarily or as a result of depleted PC stores is still speculative.

Phosphocreatine and Fatigue

During high-intensity exercise, muscle fatigue may be related to PC depletion (Hultman et al., 1967). Decreased sprinting speed may be related to a decline in energy production resulting from depletion of high energy phosphate bonds (Hirvonen, Rehunen, Rusko, & Harkonen, 1987). Type II muscle fibers, the type used predominantly during high-intensity activities, exhibit higher PC concentrations, accelerated rates of utilization, and slower recovery than type I fibers (Edstrom, Hultman, Sahlin, & Sjoholm, 1982; Greenhaff et al., 1994b; Soderlund, Greenhaff, & Hultman, 1992). It has been hypothesized that higher PC utilization and slower repletion characteristic of type II fibers may promote a reduction in force and contribute to the onset of fatigue during high-intensity exercise (Hultman & Greenhaff, 1991).

Phosphofructokinase, an important enzyme in the glycolytic pathway, may be another factor that links PC concentrations and the onset of fatigue. Phosphofructokinase appears to be inhibited by normal concentrations of PC (Storey & Hochachka, 1974). While PC cleavage and anaerobic glycolysis occur simultaneously during high intensity-exercise, PC is depleted more rapidly than glycogen forcing the contracting muscles to rely predominantly on anaerobic glycolysis for continued energy supply (Hirvonen et al., 1987; Hultman et al., 1967; Spriet, Soderlund, Bergstrom, & Hultman, 1987). When PC concentrations decline during high-intensity exercise, PFK inhibition may be released allowing accelerated glycolytic flux and greater ATP availability for continued muscle contraction. It has, therefore, been proposed that supplemental Cr may spare glycolytic substrates during predominantly

anaerobic activity. The resultant reduction in lactate accumulation and maintenance of a favorable pH could, theoretically, delay the onset of fatigue (Balsom et al., 1994; Storey & Hochachka, 1974).

Creatine Supplementation

Given the extensive roles and limited storage capacity of PC during exercise performance, supercompensation using oral Cr has become an area of interest to researchers, athletes, and manufacturers. Several companies currently market oral CrH_2O, a compound consisting of Cr stabilized with a water molecule. The product is accompanied by claims of increased peak strength, muscular endurance, body weight, and fat-free mass within a week of supplementation.

Biochemical Effects of Creatine Supplementation

Interest in the potential benefit of supercompensation with oral CrH_2O has led to investigation of tissue level effects. Oral CrH_2O supplementation has been shown to result in increases in the body's Cr pool (Chanutin, 1926; Crim, Calloway, & Margen, 1976; Hoberman et al., 1948). Increases in both plasma and total muscle Cr concentration, as determined by quadriceps femoris muscle biopsies, have been reported following CrH_2O ingestion (Harris et al., 1992). Muscle biopsies of subjects with varying, unquantified fitness levels, given CrH_2O in 5 g doses (each dose providing the Cr equivalent of approximately 1 kg uncooked beef) varying from 70 g over 3.5 days to 330 g over 21 days, revealed that Cr uptake was greatest within the first two to three days of supplementation. Increases in Cr were most substantial in subjects with the lowest initial total muscle Cr concentrations (Harris et al., 1992).

Similar oral doses of CrH_2O (20 g/day for five days) have also resulted in increased muscle PC concentration (Greenhaff et al., 1993a), and an increase in the rate of muscle PC

resynthesis following recovery from electrically evoked isometric contraction (Greenhaff, Bodin, Soderlund, & Hultman, 1994a). Further investigation, using comparable doses of CrH_2O, revealed an increase in muscle Cr resynthesis as determined by magnetic resonance spectroscopy (MRS) of the anterior tibialis muscle and quadriceps femoris muscle biopsies following 20 intense, percutaneous electrically-evoked isometric contractions (Greenhaff et al., 1993a). Muscle energetics were similarly investigated using MRS during thirty-second isometric MVCs of the ankle extensors before and after CrH_2O supplementation (Lemon et al., 1995). Results indicated increases in pre-exercise Cr/ATP ratios, total and maximal force production, glycolytic rate, and rate of oxidative phosphorylation.

Effects of Creatine Supplementation on Exercise Performance

Over the last few years, the effects of CrH_2O on exercise performance has become an area of substantial research. Following CrH_2O supplementation in moderately trained subjects given four daily doses of 5 g CrH_2O for five days, muscle torque was sustained longer without a significant change in blood lactate accumulation during repeated bouts of maximal isokinetic contractions (Greenhaff et al, 1993b). The same group of investigators observed significantly improved running times in 300 and 1000 m track events following CrH_2O ingestion (Harris, Viru, Greenhaff, & Hultman, 1993). Further research, however, indicated no significant increase in running velocity through three testing zones using the 60 m sprint (20-30 m, 40-50 m, and 50-60 m) following ingestion of 25 g CrH_2O/day for seven days (Redondo et al., 1995). More recently, peak power output during repeated sets of jump squats was increased in active males following CrH_2O supplementation. No difference in post-exercise lactate concentration, however, was observed (Volek et al., 1996).

Studies of athletes performing high-intensity, intermittent cycle exercise indicated that subjects maintained higher pedal frequency following CrH_2O ingestion (Balsom et al., 1993a). Researchers postulated a change in energy sources and a decrease in adenine nucleotide

degradation. Further investigation using the widely accepted Wingate anaerobic test (Ayalon, Inbar, & Bar-Or, 1974; Bar-Or, 1987), revealed an increase in total work output following 14 days of supplementation with 20 g of CrH_2O/day (Earnest, Snell, Rodriguez, Almada, & Mitchell, 1995b). In another study of athletes performing repeated bouts of high-intensity, intermittent cycling, investigators found that during the first two exercise bouts, peak power, mean power, and total work output increased following CrH_2O supplementation though no difference in peak lactate was observed (Birch, Noble, & Greenhaff, 1994). Similar increases in anaerobic work capacity were also attributed to CrH_2O supplementation following four bouts of cycling exercise at work rates designed to elicit fatigue within one to ten minutes (Hall, Smith, Stephens, Snell, & Earnest, 1995). However, peak power, mean power, and rate of power decline during maximal cycling exercise were not significantly altered by CrH_2O ingestion despite significantly increased total muscle Cr concentration (Ruden et al., 1996). The outcome of this investigation may have been influenced by the cross-over design with a 14-day wash-out period which may have been inadequate for ensuring complete removal of supplemental Cr (Greenhaff, 1995).

During continuous exercise there are brief periods of high-intensity efforts during which time anaerobic systems are used such as at the start of a race or during a hill climb (Fox et al., 1993). Therefore, the potential ergogenic effect of CrH_2O on continuous exercise was investigated. In one study, no significant improvements in performance times, relative oxygen consumption (VO_2), or blood lactate were documented following a CrH_2O-supplemented exhaustive treadmill run or during a 6 km run on a forest track with variable terrain (Balsom, Harridge, Soderlund, Sjodin, & Ekblom, 1993b). Time to exhaustion and blood lactate accumulation during intermediate length treadmill runs, designed to fatigue subjects within 90 seconds, were also unaffected by CrH_2O supplementation (Earnest, Rash, Snell, Almada, & Mitchell, 1995a). Performance and energy metabolism during intermittent submaximal treadmill runs were, similarly, unaffected in subjects of varying fitness levels

ingesting CrH_2O (Green et al., 1994).

While it appears that CrH_2O supplementation may improve performance of short-term anaerobic work that primarily utilizes large muscle groups of the lower body, the effects of CrH_2O on activities that rely primarily on upper body movement has gained only minimal attention. Only five investigations addressing oral CrH_2O supplementation and upper body anaerobic performance have been published. Two of these five studies addressed sports involving whole body anaerobic performance rather than predominantly upper extremity strength. Supplemental CrH_2O given to elite swimmers resulted in no improvement in velocity of 25, 50, and 100 m swim sprints (Burke, Pyne, & Telford, 1995). Similarly, in a study of competitive rowers, CrH_2O supplementation did not result in significantly improved rowing times (Rossiter, Cannel, & Jakeman, 1996). Weight-trained male subjects ingesting daily doses of a high carbohydrate, high protein supplement with 20 g CrH_2O/day, experienced no significant enhancement of average peak power, peak force, or mean force during maximal bench press repetitions (Grindstaff et al., 1995). Absolute peak power, however, was significantly increased following supplementation. Following three more weeks of the same regimen (28 days total), improvements in absolute and relative power and force and in total work output were evident in both placebo and supplemented groups suggesting a training effect rather than an ergogenic influence (Almada et al., 1995). In a recent investigation of normally-active males taking either a placebo or CrH_2O, a significant improvement in the total number of bench press repetitions was observed following CrH_2O (Volek et al., 1996).

To date, no research has been published regarding the effect of oral CrH_2O on explosive, upper body, sport-specific movements such as overhand throwing, swinging a bat or racquet, or spiking/serving a volleyball. In addition, the majority of existing studies regarding CrH_2O have focused primarily on exercise response of males with limited comparison between gender (Brees et al., 1994; Ruden et al., 1996). While research on gender-specific effects

of Cr supplementation on athletic performance is lacking, there is evidence of higher total muscle Cr/PC content in female versus male non-athletes (Forsberg, Nilsson, Werneman, Bergstrom, & Hultman, 1991). It is unknown, however, whether the relative quantity of PC stored in muscle relates to efficacy of CrH_2O supercompensation. Because of inherent gender differences in lean body mass (McArdle et al., 1991) and the possible gender difference in Cr/PC muscle content relative to tissue weight, the efficacy of Cr supplementation on the exercise response of females should be quantified.

In summary, the effects of Cr supercompensation on exercise performance remain equivocal. Supplementation with CrH_2O appears to alter muscle energetics possibly resulting in more efficient use of metabolic fuels and a delay in muscle fatigue (Greenhaff, et al., 1993a, 1993b; Lemon et al., 1995). It appears that supplementation with 25-30 g of CrH_2O daily for five to seven days may improve performance of high-intensity, short-term, anaerobic work utilizing large muscle groups (Balsom et al., 1993a; Earnest et al., 1995b; Hall et al., 1995; Harris et al., 1993). There is little evidence, however, that supplementation with CrH_2O has any buffering effect during anaerobic activities (Birch et al., 1994; Greenhaff et al., 1993b; Volek et al., 1996). It also remains unclear whether oral CrH_2O can improve high-intensity performance of the upper extremities or whether similar effects are observed in females. Furthermore, there remains a strong reliance on published abstracts with limited peer-reviewed, exercise performance-related publications in existence (Balsom et al., 1993a, 1993b, 1994; Earnest et al., 1995a, 1995b; Greenhaff, 1995; Greenhaff et al., 1993b; Maughan, 1995; Volek & Kraemer, 1996). Therefore, investigation on the effects of CrH_2O supplementation on upper body anaerobic response in females is warranted.

CHAPTER III

EXPERIMENTAL PROCEDURES

Description of Subjects and Movements Tested

Following written informed consent and approval from the Montana State University-Bozeman Human Subjects Committee, 24 college-aged females, who met the inclusion criteria of participation in upper extremity strength training and either recreational or competitive overhand sports, took part in this study. Inclusion criteria were based on prior research indicating overall strength and biomechanical differences between throwing athletes and non-throwing athletes (Brown, Niehues, & Harrah, 1988; Cook, Gray, & Savinar-Nogue, 1987; Ellenbecker, Davies, & Rowinski, 1988; Ng & Kramer, 1991; Perrin, Robertson, & Ray, 1987; Wooden, Greenfield, & Johanson, 1992). Subjects met criteria for involvement in overhand sport based on reported frequency of participation in such sports and on observed throwing accuracy. All testing was conducted at the Montana State University-Bozeman Human Performance and Ergonomics Laboratory.

Testing included two movements, elbow flexion (EF) and shoulder internal rotation (IR). Elbow flexion is commonly used to evaluate concentric (CON) and eccentric (ECC) strength of the biceps brachii, brachioradialis, and brachialis muscles (Adams, 1994; Rutherford & Corbin, 1994). The movement is also commonly used as a component of strength conditioning programs (Adams, 1994; DeLorme & Watkins, 1951; Fox et al., 1993; Heywood, 1991; Wilmore & Costill, 1988; Withers, 1970). Therefore, EF was selected to evaluate the efficacy of CrH_2O supplementation in strength conditioning of the upper extremities.

In contrast to EF, which incorporates a finite number of muscles, an overhand throwing motion utilizes numerous muscle groups of the upper body (Bartlett, Storey, & Simons,

1989). The muscles responsible for rotating the shoulder internally, a movement dominant in the overhand throw, are active during the upper extremity projectile motions used in a variety of sport movements such as the baseball pitch, tennis serve, volleyball spike and serve, water polo throw, and javelin throw (Cohen, Mont, Campbell, Vogelstein, & Loewy, 1994). The acceleration of such movements is dependent upon explosive contraction of the internal rotators (coracobrachialis, biceps-short head, subscapularis, teres major, latissimus dorsi, anterior deltoid, and pectoralis major) which may either provide the power for the movement, stabilize the glenohumoral joint during the movement, or both (Atwater, 1979; Cohen et al., 1994; Perry, 1983; Toyoshima & Hoshikawa, 1974). Additionally, upper extremity peak torque has been shown to be positively correlated with throwing speed in competitive athletes (Bartlett et al., 1989; Pedegana, Elsner, & Roberts, 1982). Thus, shoulder IR was selected to evaluate the potential use of CrH_2O supplementation in a variety of overhand throwing skills.

Pre-testing Procedures

Prior to initiation of testing, supine, hyperventilation, and standing modified Mason-Likar twelve-lead electrocardiogram (ECG) recordings (Dubin, 1989; Marquette Max-1, Marquette Electronics Inc., Milwaukee, WI), heart rates, and blood pressures were obtained from each subject to identify any contraindications to participation (American College of Sports Medicine, 1995). Height (Ht; cm) and weight (Wt; kg) were determined using a calibrated Detecto physician's beam scale (Cardinal Scale Manufacturing Co., Webb City, MO). Body composition was evaluated via the seven-site skinfold technique (Brozek, Grande, Anderson, & Keys, 1963; Jackson & Pollock, 1977; Pollock, Schmidt, & Jackson, 1980) using a Lange skinfold caliper (Cambridge Scientific Industries, Inc., Cambridge, MD). After obtaining three measurements at each site using appropriate landmarks on the right side of the body, the mean measurement at each site was used to calculate percent body fat (BF; %) and lean

body mass (LBM; kg) via the following equations:

Eq. 1 D_b = 1.0979 - 0.0004697(sum of 7 sites) + 0.00000056(sum of 7 sites)^2 - 0.00012828(age)

Where:
- D_b = body density
- 1.0979 = regression coefficient for variance in body circumference
- 0.0004697 = regression coefficient for variance in sum of skinfolds
- 0.00000056 = regression coefficient for variance in squared sum of skinfolds
- 0.00012828 = regression coefficient for variance in age

Eq. 2 %BF = $\frac{4.570}{D_b}$ - 4.142 x 100

Where:
- 4.57 = constant for density of fat tissue
- 4.142 = constant for density of fat-free tissue

Eq. 3 LBM = (100 - %BF) x Wt (kg)

Testing

The study included five testing sessions (Figure 4). The first three sessions were conducted for the purpose of habituation; the last two sessions constituted data collection.

Figure 4. Time Line for Completion of the Five Testing Sessions

Day 1: Test 1	Day 3: Test 2	Day 6: Test 3	Day 13: Test 4	Day 20: Test 5
Neither CrH_2O nor P was delivered	*Neither CrH_2O nor P was delivered*	*7-day dietary habituation began following testing*	*CrH_2O or P began following testing*	*CrH_2O or P was completed prior to testing*

At each session, peak strength during EF and IR was evaluated using the one repetition maximum (1RM), one of the most operational definitions for strength (Eq. 4; DeLorme & Watkins, 1951). One repetition maximum was expressed as the isotonic resistance (Nm) at which each subject could only complete one repetition. Strength was also expressed as the

total number of repetitions that could be completed at 70% of 1RM, a workload selected to

Eq. 4 1RM (Nm) = Nm at RM between 2-20 repetitions/[100% - (RM x 2)]

facilitate sport-specific testing, with nine to twelve repetitions per set typically employed in resistance programs designed to achieve both strength and endurance gains (Dons, Bollerup, Bonde-Petersen, & Hancke, 1979; Withers, 1970). All testing was conducted using a LIDO WorkSET™ dynamometer (Loredan Biomedical, Inc., West Sacramento, CA). The LIDO WorkSET™ facilitates isokinetic (IK), isotonic (IT), and isometric evaluation throughout concentric (CON), eccentric (ECC), and continuous passive motion modes. Modes utilized in this study included IK (CON/ECC) and IT (CON). The LIDO WorkSET™ dynamometer has been found to have test-retest reliabilities of 0.82-0.96 for peak torque and average peak torque and a high degree of internal validity (R^2=1) with regard to torque, power, and work (Matheson et al., 1992). Test-retest reliability coefficients for this study were determined via intraclass correlation which employs ANOVA for calculation of R (see Appendix C, Table 1). The LIDO was interfaced with a personal computer via a digital to analog board and Labtech Notebook (version 6) software (Laboratory Technologies Corporation, Wilmington, MA) to facilitate collection of position and torque data at a sampling rate of 150 Hz. Isotonic strength testing was performed to facilitate measurement not only of EF and IR strength, but also of velocity throughout the execution of shoulder IR (Adams, 1994). Inclusion of IK strength testing enabled measurement of torque throughout the active EF range of motion (ROM) while the dynamometer maintained a constant angular velocity (Hislop & Perrine, 1967).

Torque "overshoot" or impact torque, evidenced by prominent initial and terminal spikes in torque output curves, was disregarded in the determination of peak IK torque (Perrine & Edgerton, 1978; Sapega, Nicholas, Sokolow, & Saraniti, 1982). It is thought that these spikes do not represent intermittent surges of muscular contractile force but, rather, forces

associated with the initial accelerations, final decelerations, and subsequent velocity fluctuations of an initially overspeeding lever system (Sapega et al., 1982). Compensation for the effect of gravity on the LIDO lever arms was accomplished internally by the dynamometer except during IK testing. Compensation for gravity during IK testing was made by hand calculation based on torque caused by gravity on the lever arm in the position approximating that for peak torque during EF.

Habituation Phase

The first three of the five total testing sessions were designed to obtain proper equipment settings, familiarize subjects with the procedures for testing and supplementation, and promote biomechanical efficiency during execution of both movements tested. Appropriate settings for EF on the LIDO were obtained and recorded after instructing subjects on proper positioning. Positioning for EF testing required standing with the feet shoulder width apart, stabilizing the elbow against the iliac crest, and keeping the shoulders back and the head facing straight forward. Range of motion for EF testing was measured from the point of maximal flexion to that of maximal extension. The lateral epicondyle of the dominant limb was located and aligned with the center of rotation on the lever arm of the LIDO. Proper lower body positioning for testing shoulder IR was determined by measuring the distance between the leading and trailing foot at the point of ball release during a typical overhand throw. This measured distance was marked on the floor parallel to the LIDO to facilitate lower body positioning during testing of IR that duplicated that during the subject's overhand throw. With the dominant arm in 90° of elbow flexion, 90° of shoulder abduction, and approximately 20° of forward flexion to facilitate testing in the scapular plane (Ellenbecker, Feiring, & DeHart, 1992), the olecranon process of the dominant arm was located and aligned with the center of rotation on the lever arm of the LIDO. Internal rotation was evaluated from each subject's point of maximal external rotation, with the arm in 90° of

shoulder abduction and 90° of elbow flexion, through horizontal forward (forearm parallel with the ground; Hinton, 1988). Shoulder IR was evaluated without immobilizing the lower extremity or the torso. Aggressive verbal cues were provided to minimize involvement of muscles other than those responsible for IR.

Following determination of appropriate settings, habituation testing sessions were conducted. On the day of the third habituation testing session, all subjects began consumption of 6 oz herbal tea, five times daily for one week to become familiar with supplementation procedures. Following habituation testing sessions, subjects were pair-matched based on Ht, Wt, BF, LBM, and age (years), and randomly assigned to receive either CrH_2O (n=11) treatment or P (n=13).

Testing Sessions

Subjects began each of the five testing sessions by warming-up with three submaximal EF IK CON/ECC contractions (approximately 50% of maximal voluntary contraction, MVC) on the dominant side at 90°/s in a standing position (Adams, 1994; Morris, Lussier, Bell, & Dooley, 1983; Osternig, 1986; Sale, 1991; Stafford & Grana, 1984). Following a standard two-minute rest period, subjects completed one MVC and the peak CON and ECC torques were recorded as EF IK_{CON} (Nm) and EF IK_{ECC} (Nm), respectively.

Evaluation of EF_{1RM} began with a warm-up of three submaximal CON contractions using approximately 50% of estimated EF_{1RM} (or 50% of previously determined 1RM) on the dominant side. Approximation of EF_{1RM} was made based on the linear relationship between the intensity and the number of repetitions performed (see Eq. 4; DeLorme & Watkins, 1951; Hoeger, Barette, Hale, & Hopkins, 1987; Landers, 1985). Approximated EF_{1RM} was then verified by counting the number of repetitions that could be completed at the calculated load. Load adjustments were made as necessary, until EF_{1RM} (Nm) was determined. Subjects then completed successive EF repetitions in the IT mode at 70% of 1RM until volitional