CHANGES IN STRENGTH AND FUNCTIONAL ABILITY
IN OLDER ADULTS IN RESPONSE TO
CREATINE SUPPLEMENTATION AND RESISTANCE TRAINING
by
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The purpose of this study was to investigate the effects of creatine monohydrate (Cr.H_2O) supplementation in conjunction with six weeks of resistance training on the strength and functional abilities of older adults. Recently, several studies have looked at the effectiveness of Cr.H_2O supplementation in enhancing performance and recovery during several types of high-intensity short-term (HI-ST) activity. However, few studies have examined the effects of supplementation in conjunction with resistance training and none have used older subjects. Fatigue during HI-ST activities such as a resistance training is largely the result of the inability of phosphocreatine (PCr) hydrolysis to maintain a high adenosine triphosphate (ATP): adenosine diphosphate (ADP) ratio, due to depletion of the limited PCr stores in the muscle. Oral Cr.H_2O supplementation can significantly increase both muscle and whole body creatine stores. Cr.H_2O supplementation may enhance performance in conjunction with resistance training as a result of (1) an increase in the initial muscle PCr pool (2) enhanced PCr resynthesis during recovery and possibly (3) through an increase in protein synthesis. In older adults the age-associated loss of muscle strength, which progresses rapidly after the age of 50, is related to an individual's ability to maintain an independent and healthy lifestyle.

In the present study 53 males and females aged 50 - 75 years of age volunteered to participate. The study involved a double blind, repeated measures design, in which subjects self-administered four, 5 gram servings for one week followed by five weeks of one 5 gram serving per day of either Cr.H_2O (Cr group, n=27) or a placebo (P group, n=26). During the six week supplementation period all subjects participated in a three-session per week whole body resistance training program. Measurements for body weight (WT) and chest press repetitions to failure (REPS) using a pre-established 10 RM weight were taken prior to (T1) after one week (T2) and following (T3) the six week training/supplementation period.
and T3 measurements were also taken for grip strength (GRIP), and the constructs FUNCTION (combining the chair rise and medicine ball lift functional tests) and STRENGTH (combining 10 RM tests for chest press, seated row, leg extension and leg curl).

ANOVA analyses revealed all subjects performed considerably more repetitions for REPS at T2 AND T3 but no significant differences were seen between the Cr and P groups for this variable at T2 or T3 ($\alpha=0.05$). MANOVA analyses of the measurements GRIP, STRENGTH, and FUNCTION showed subjects improved significantly on all three of these measures as a result of training but these improvements were not significantly different between treatment groups. However, post-hoc analyses revealed males and females in the Cr group varied in their response to creatine supplementation when compared independently to their PI group counterparts. The Cr males demonstrated a 31% increase in STRENGTH compared to a 21% improvement experienced by the PI males. This approximate 10% greater level of improvement for the Cr males was significantly different from the PI males ($p=0.009$). The females in the Cr and PI groups experienced a 32% and 30% improvement in STRENGTH, respectively. To the author's knowledge this study represents the first time the effects of creatine supplementation have been studied in an older adult population and the first to show a significant difference between males and females in response to supplementation combined with resistance training.
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1.1 Introduction to the Problem

There currently is a glut of anecdotal information heralding the benefits of supplementation with creatine monohydrate, a naturally occurring amino acid complex, touted to be everything from a miracle energy supplement to the safe alternative to anabolic steroids. However, very little published information exists concerning the use of this substance especially in conjunction with exercise. Results from the limited scientific investigations that have studied creatine supplementation are in-conclusive. However, the information currently available from both the scientific community and the public appears to indicate that creatine indeed has an ergogenic effect. The questions that remain to be answered are, for whom does it work, when, and under which specific exercise situations. Lastly, is it safe?

Based on the information currently available from within both the scientific and non-scientific communities it appears the greatest benefit of creatine as an ergogenic substance will likely be realized when combined with resistance training. Specifically, individuals partaking in regular high intensity resistance training may likely experience a greater increase in strength and possibly muscle hypertrophy over time when their total training regime includes creatine supplementation.

It has been well documented that muscle mass and muscle strength decline with age (Campbell et al., 1995; Hyatt et al., 1990; Larsson et al., 1979; Young, 1992). These natural and disuse related changes in muscle physiology and strength especially following 50 years of age are of paramount concern in light of current demographics indicating a rapidly aging population world wide. In older adults measures for dynamic and isometric muscle strength are strongly related to functional ability, physical frailty and independence (Bassey et al., 1992; Fiatarrone et al., 1994). In order to combat the enormous health care costs associated with an inactive older population necessity has demanded a paradigm shift in the current
health care model for the 21st century from a philosophy of rehabilitation to one of "prehabilitation". Consequently, health care professionals from a variety of disciplines are focusing on pro-active strategies to combat among other concerns, the age associated changes in strength and muscle mass. Creatine supplementation in conjunction with regular resistance training may prove to be one such strategy.

Creatine is a naturally occurring amino acid complex that has numerous functions in the body including a major role in short term energy metabolism. It has been demonstrated previously that oral supplementation with digestible creatine monohydrate will result in a significant increase in the intramuscular concentration of creatine in humans (Harris et al., 1992, Hultman et al., 1996). From this observation it has been theorized that higher concentrations of creatine in the muscle may provide an ergogenic benefit during short term, high intensity activities (such as resistance training) due to a greater availability of phosphocreatine which may promote greater resynthesis of ATP during and in between repeated bouts of such activities. During resistance training this would increase an individuals potential to perform a greater total training volume at a higher intensity for any given training micro or macrocycle thus leading to a higher degree of adaptation within that period. Although highly speculative there is also limited evidence supporting the hypothesis that creatine supplementation may directly promote protein synthesis within the muscle either with or without resistance training. This hypothesis will remain speculative until further research has been conducted.

The health care field is slowly adapting a pro-active approach to address the health and medical concerns of our ever increasing aging population. In keeping with this paradigm shift the following investigation will shed light on some of the questions concerning creatine supplementation while examining a specific prehabilitative strategy for the health care issues surrounding the changes occurring with age in skeletal muscle morphology and physiology and the subsequent effects on strength and functional ability.
1.2 Purpose

The purpose of this study was to determine the degree to which six weeks of high intensity resistance training combined with oral Cr.H₂O supplementation could affect performance on select measures for muscle strength and functional abilities in older adults, over and above the improvements expected in these variables with resistance training alone.

1.3 Hypothesis

One week of Cr.H₂O loading (20 grams/day) followed by 5 weeks of a maintenance dose (5 grams/day) in conjunction with high intensity resistance training would result in a significant increase in muscle strength and functional abilities when compared to the placebo treatment. Specifically, the following hypotheses are made:

1) Gain in body weight (WT) at T2 and T3; **Creatine Group (CR) > Placebo Group (PL)**

2) Improvement in repetitions to failure (REPS) at T2 and T3; **CR > PL**.

3) Improvement in grip strength (GRIP) from T1 to T3; **CR > PL**.

4) Improvement in time for functional tests (FUNCTION) from T1 to T3; **CR > PL**.
   (FUNCTION index combines the chair rise [CR] and med-ball lift [MB] tests).

5) Increase in whole body strength (STRENGTH) from T1 to T3; **CR > PL**.
   (STRENGTH index combines the 10 RM strength tests chest press (CP), seated row (SR), leg extension (LE) and leg curl (LC).

6) Regardless of supplementation ingested all subjects will improve on all dependent variables as a result of six weeks of high-intensity resistance training.
1.4 Limitations

1. It is assumed subjects exerted maximal effort during all testing sessions and throughout the resistance training program.

2. Intramuscular creatine stores were not measured.

3. It is assumed that all subjects properly followed the supplementation and resistance training protocol.

1.5 Delimitations

1. Subjects for this study will be recruited from the Changing Aging Adult Fitness Program at The University of British Columbia.

2. All subjects are active, healthy independent males and females between the ages of 50 and 75 years.

1.6 Justification

The importance of this research becomes apparent in light of current demographic trends indicating a rapidly aging population. It is of prime importance that we identify every safe prevention strategy that may assist in decreasing the health care costs associated with the loss of strength and functional abilities in this segment of the population. As life expectancy continues to rise it is of equal importance that we identify positive lifestyle strategies to assist older adults in living an active and independent life. Observations made during this study will add to the present base of information on resistance training, creatine supplementation and how older adults respond when these two methods are combined.
CHAPTER 2

2.0 Review of Literature

2.1 Introduction

It is well documented that muscle mass, muscle strength (Campbell et al., 1995; Hyatt et al., 1990; Larsson et al., 1979; Young, 1992) and bone mass (Garn et al., 1967; Lanyon, 1996; Sinaki, 1989) decline with age. Throughout life, strength is required to perform everyday functions such as rising from a chair, climbing stairs or lifting and carrying loads. However, younger individuals take many of these activities for granted since, in the absence of a dehabilitating disease or chronic disorder they are not limited by muscular strength which generally peaks by the third decade, plateaus between the fourth and fifth decades and begins to decline following the fifth decade of life (Larsson et al., 1979; McCartney et al., 1995). By 70 years of age the average individual will have lost approximately one third of his or her strength (roughly 1.5% per annum after the age of 50) and possibly as much as 40% (Danneskiold-Samsoe et al., 1984; Skelton et al., 1994).

In older adults measures for dynamic and isometric muscle strength are strongly related to functional ability, physical frailty, independence, bone mass and a concomitant risk of injury due to a fall (Bassey et al., 1992; Fiattarone et al., 1994). In 1983 in the United States, medical expenditures for the treatment of osteoporotic hip fractures accounted for nearly 4 billion dollars in health care costs (Kannus et al., 1996). By 1995 that figure had risen to more than 8 billion with the total treatment costs for all osteoporotic fractures estimated at 13.8 billion dollars (Ray et al., 1997). By the year 2000 in the U.S.A. over 70% of all health care costs will be spent on people over 50 years of age with fall-related fractures accounting for almost one third of that amount. (Kannus et al., 1996). By the year 2000 in Canada, total health care costs are expected to account for 32% of the federal budget (Govindasamy and Paterson, 1994). Based on current North American demographics, these
trends will likely continue and worsen since by the end of this century over 50% of the population in North America will be over the age of 50 with more than 120,000 people having celebrated their 100th birthday (Dr. Ken Kambis, personal communication, February, 1996). We are on the verge of a health care crisis. Risk factors related to an increase chance of fall-related injury include an age associated loss in muscle mass, strength, balance, coordination and loss of skeletal bone mass (Lauritzen, 1996). For many years it was believed that these risk factors were a natural characteristic of the aging process. In recent years certain events and much research have shed considerable light on this subject.

For the first time, extended manned space flights have provided us with a realistic model for examining the aging process. Astronauts returning from space had experienced many of the classic physical signs of aging, including muscle and bone atrophy and significant loss of muscle function including strength, balance and coordination. These observations sparked a fresh interest in the area of aging and activity. Not long after these events researchers took an in-depth look at the role of disuse in the aging process as it was understood at that time. One such study, by Saltin and Grimby (1968) examined the effects of 24-hour complete bed rest for a period of 21 days in five healthy young males. They reported that the loss of physical fitness experienced by these individuals after the 21 days was equivalent to almost 20 years of aging.

We have discovered much in the 30 years since that study. Several researchers have demonstrated what was formerly considered to be an age related loss of bone mass is partially a function of activity level. Individuals in their seventh, eighth and even ninth decade of life can not only greatly reduce the amount of age-related bone loss through exercise, but also may increase their bone mineral content at these ages (Aloia et al., 1978; Dalsky et al., 1988; Smith and Gilligan, 1996). Studies examining the effects of disuse, and overuse (exercise) on muscle mass and strength losses have found equally impressive results. Several researchers have reported that older adults are able to tolerate HI-ST exercise such as resistance training with improvements in muscle strength and muscle mass equal to and in
some cases greater than those seen in younger subjects (Fiattarone et al., 1990; Greig et al., 1994; Skelton et al., 1995). For older adults, these training benefits have resulted in improved functional abilities (Fiattarone et al., 1990; McCartney et al., 1995) and decreased risk of falls and/or injury due to a fall (Myers et al., 1996).

As was previously mentioned, muscle size and strength begin to decrease following the fifth decade of life. It has been demonstrated that muscle disuse due to a decreased level of physical activity can partially account for the amount and rate at which this loss will occur (Grimby, 1988; Klitgaard et al., 1990). However, there is still a natural pattern of physiological and morphological change taking place in the muscle during the aging process that also contributes to this phenomenon.

Several investigators have observed that with aging there is a decrease in muscle cross-sectional area (Fiattarone et al., 1990; Fiattarone et al., 1994; Grimby, 1988; Hyatt et al., 1990; Larsson et al., 1979). Histochemical analysis has shown that this is in part due to a reduction in the total number of muscle fibers with the magnitude of the reduction estimated at about 30% during adult life (Grimby and Saltin, 1983; Larsson et al., 1979; Lexell et al., 1983). A reduction in the size of the large type-II muscle fibers (T-II), primarily type IIB fibers (T-IIB) (Aniansson et al., 1986; Grimby et al., 1982). T-II (including T-IIA and T-IIB) muscle fibers is also responsible for force loss, especially during high intensity, short term muscular activity such as sprinting, jumping, punching, throwing, lifting, etc. As we age these types of activities are performed less frequently to the point where many individuals rarely if ever participate in activities in which they are involved. Therefore, the loss of strength associated with aging is due to a combination of both disuse and the natural regression in muscle fiber number and T-II fiber size.

In summary, the literature suggests that resistance training with older adults can enhance muscle strength and muscle size. Resistance training is considered a HI-ST activity known to promote positive adaptations in skeletal muscle including increased cross-sectional area in both T-I and T-II muscle fibers, with T-II fibers demonstrating a greater degree of
adaption. Such adaptations combine to enhance a muscle's ability to produce force resulting in a net strength gain in the individual (McArdle et al., 1986). Strength is highly related to independence, functional ability, and a decreased chance and severity of injury associated with a fall.

It is clear that older adults should participate in some form of high intensity resistance training on a regular basis in order to live a healthy and independent life. However, what training methods maximize the benefits of resistance training are not clearly identified for the aging population. While scores of researchers have investigated methods for maximizing strength in younger individuals, we have only begun to understand how these same techniques may benefit an older population.

In the past half decade considerable attention has been given to a relatively new ergogenic aid which may be of significant value to any individual for whom improving strength is a major concern. Preliminary observations on the benefits of Cr.H₂O supplementation in conjunction with resistance training are impressive, though not yet conclusive; further studies are indicated. Thousands of recreational and competitive athletes currently include Cr.H₂O supplementation as part of their total training regime, but it is still an open question as to the efficacy of such an approach.

Cr.H₂O is one of two commercially available, digestible sources of creatine (N-aminoiminomethyl]-N-methyl glycine). The other is creatine citrate. Cr is a nitrogenous organic compound that can either be obtained in the diet from meat, chicken or fish (Greenhaff, 1995) or synthesized de novo in liver (primary location), kidneys and pancreas from the pre-cursor amino acids arginine, glycine and methionine. Regardless of its source, Cr is transported in the blood to its primary site of storage, skeletal muscle. Approximately 95-98% of the total Cr in the body is found in skeletal muscle of which approximately one third is in its free (Cr) form. The remaining two thirds exist in the phosphorylated, phosphocreatine (PCr) form (Balsom et al., 1994). On average, the concentration of Cr in skeletal muscle is approximately 124 mmol/kg/dry muscle. However, vegetarians are
reported to have a slightly lower concentration of Cr in muscle than their meat-eating counterparts (Volek and Kraemer, 1996).

Cr has numerous functions in the body and serves a major role in energy metabolism. As the phosphorylated (PCr) form it is used to rapidly replenish ATP through the creatine kinase reaction, most notably during conditions of maximal energy production. The ability to maintain maximal force output during HI-ST activity is largely dependent on the availability of PCr. Thus, pre-activity PCr levels are considered to be a limiting factor during this type of activity (Balsom et al., 1994). Several investigators have shown that the concentration of intramuscular Cr is significantly augmented when the normal intake is exceeded via Cr.H2O supplementation. The normal turnover rate for Cr in the body is 1-2 grams per day. This represents the average daily requirement which is met via exogenous sources and/or endogenous production depending on the amount of exogenous Cr in the diet (Green et al., 1996; Greenhaff, 1995; Harris et al., 1992; Hultman et al., 1996; Maughan, 1995; Toler, 1997). Since performance during HI-ST activity is directly related to the concentration of PCr in muscle, it can be hypothesized that an individual should be able to maintain maximal force output for an extended period of time following augmentation of muscle PCr levels through supplementation with Cr.H2O. Relating this information specifically to resistance training we can suggest the following: Cr.H2O supplementation could likely result in more rapid improvements in strength following training as the ability to delay fatigue would directly affect the volume of work that could be performed in a single exercise set and/or training session. Over a given period of time, this greater training stimulus could result in a greater net increase in adaptation to training. This is the basic premise behind the use of Cr.H2O as an ergogenic aid. Several researchers have suggested that Cr may also stimulate protein synthesis directly in the muscle cell, enhancing adaptations that may occur in response to resistance training (Bessman and Savabi, 1988; Earnest et al., 1995; Vandenberghe et al., 1997; Volek et al., 1997).

Whether Cr.H2O supplementation is truly effective is an unresolved issue, but
preliminary work has already shown favourable results. Unfortunately, while the published work suggests a positive outcome for young people, little is known regarding creatine supplementation for those whom the loss of muscle strength is considered a major risk factor for potentially dehabilitating disorders and/or disease states. Thus, the following study will attempt to determine how a group of healthy independent older adults respond to a regime of Cr.H2O supplementation in conjunction with high-intensity resistance training. If the results of this investigation support the practice of combining Cr.H2O supplementation with resistance training in older adults both researchers and practitioners in this field will have another valuable method to combat the enormous health care costs associated with the loss of strength with age.

2.2 Background

This review of literature will provide a brief historical overview of relevant research on Cr since its discovery, then focus on recent investigations exclusively studying the effects of Cr supplementation using human subjects. Research findings outlined in the preceding chapter regarding exercise and aging will be referred to throughout this review but will not be further expounded as they have already gained widespread scientific acceptance.

2.3 Historical Overview

Cr was first identified in 1832 by a French scientist named Chevreul. Fifteen years later, Lieberg reported that the Cr content in the meat of wild foxes killed during the chase was 10 times greater than that found in domesticated foxes. He concluded that Cr accumulated in muscle as a consequence of physical activity (as cited by Sahelian and Tuttle, 1997). In the nineteenth century Hientz and Pettenkofer discovered the substance creatinine in the urine, and along with Lieberg made the initial connection that creatinine in the urine was related to Cr stored in the muscles (as cited by Balsom et al., 1994). Currently it is known that creatinine is a by-product of creatine breakdown and is used as a marker for,
among other things the rate of creatine turnover in the body and an indicator of Cr retention during supplementation (Balsom et al., 1994). Between 1910 and 1930 numerous Cr feeding studies were conducted. It was observed that not all of the ingested Cr could be accounted for by the amount of creatinine present in the urine. For the first time the hypothesis that supplemented Cr could be retained by the body was made (Balsom et al., 1994). After this period little significant information was reported and/or published regarding Cr and its possible benefit as an ergogenic aid. Then, in 1981 a group of researchers in Helsinki studied the effects of low dosage Cr supplementation (1.5 grams/day) on gyrate atrophy of the choroid and retina. This disease is characterized by, among other things a morphologically marked progressive atrophy of T-II skeletal muscle fibers. They observed that all subjects demonstrated significant hypertrophy in T-II muscle fibers biopsied from the vastus lateralis muscle (Sipila et al., 1981). However, not until the study by Harris, Soderlund and Hultman in 1990 did the notion of Cr as an ergogenic aid truly take root. This group established that total Cr content significantly increased in the quadriceps femoris muscle after supplementation of 20-25 grams of Cr per day for 2 or more days. Moreover, they demonstrated that intense exercise augmented the increase in total Cr content (Harris et al., 1992). Shortly after these observations the first report of Cr being used as an ergogenic aid came during the 1992 Summer Olympic Games in Barcelona when British sprinters reported they had used Cr in preparation for, and during the Games (Gaie, 1996).

2.4 Creatine Retention in Muscle Following Supplementation

While there has long been a belief that creatine supplementation could increase muscle creatine concentration, performance enhancement with supplementation has only recently been demonstrated. In terms of enhanced energy metabolism during exercise, it is the specific dosage/supplementation protocol, the resulting site of Cr retention, and its storage form that are critically important (Hultman, 1996). The first investigation to clarify these issues was that by Harris et al., (1992). This study was the first to show total
intramuscular Cr content (TCr) including both PCr and free creatine (Crf), was enhanced following supplementation. They also identified the dosage and supplementation protocol which resulted in the greatest amount of Cr retention in muscle by examining the effects of varying dosages and timing of dosages over two to seven day supplementation periods. From this they concluded the following: First, a significant increase in the TCr content of the quadriceps femoris muscle will result from a supplementation protocol of 5 grams of Cr. H2O taken orally four to six times per day for 2 or more days (increases ranged from 20-50%). This increase was highest in subjects who, prior to supplementation had the lowest TCr values. Approximately 20% (non-significant) of the increase in TCr was in the form of PCr with the remainder being free creatine (Crf). Second, Cr uptake in the muscle was highest during the first two days. Third, one hour of hard, single leg exercise per day in conjunction with supplementation resulted in an average mean increase of 54 % (SD ± 24%) for TCr in the exercised leg with no change in the contralateral leg. Finally, there were no side effects noted in any of the subjects as a result of participation in the study.

Results from this study are of importance when we reflect on the fact that a limiting factor, if not the limiting factor in muscle fatigue during HI-ST exercise is the availability of PCr for the rapid re-phosphorylation of ATP during and between consecutive bouts of exercise. Theoretically, based on these observations it should be possible to delay fatigue during HI-ST activity by augmenting TCr stores via the supplementation protocol identified in this investigation.

Since this study was published several researchers have found similar results. Hultman et al. (1996) reported that six days of Cr.H2O supplementation at a rate of 20 grams per day (4 x 5 gram doses) resulted in a 20% significant mean increase in TCr. Approximately 20% was in the form of PCr and the remainder was Crf. These values are in direct agreement with those reported by Harris et al. (1995). A further purpose for the Hultman et al. (1996) investigation was to examine whether or not any observed increase in muscle TCr levels following the initial 6 day "loading phase" could be sustained by a smaller
dosage "maintenance phase". After the initial six day loading one group of subjects stopped supplementation while a second group continued supplementation at a dosage of 2 grams per day for an additional 22 days. They reported that TCr levels for the load and maintenance group remained elevated at the post-loading level for the entire 28 day period, while TCr levels for the other group had decreased almost to pre-supplementation levels by the end of the 28 days. The maintenance dosage of 2 grams per day was chosen since this value represents the average daily rate of Cr conversion to creatinine.

Green et al. (1996) investigated both the effect of Cr supplementation alone and in conjunction with carbohydrate (CHO) ingestion on TCr accumulation. A previous investigation by Haughland and Chang (cited in Hultman et al. 1996) using rat skeletal muscle had shown that Cr uptake in muscle was slightly enhanced in the presence of insulin. Green et al. reported that TCr retention in muscle was 60% higher when supplementation was combined with CHO compared to CrH₂O supplementation. Green et al (1996) were the first to demonstrate a synergistic effect of CHO on Cr retention in the muscle following supplementation.

Several researchers have reported that Cr retention following supplementation is inversely related to the initial TCr levels in the muscle such that individuals with lower levels exhibit the greatest increase (Balsom et al., 1994; Bessman and Savabi, 1988; Greenhaff, 1995; Volek and Kraemer, 1996). The upper limit for Cr retention is approximately 160 mmol of Cr per kg of dry muscle though individual variances do occur. This value refers to TCr content which includes both PCr and Crf (Harris et al., 1992).

2.5 Creatine Supplementation and Exercise

A number of researchers have observed the effects of CrH₂O supplementation on performance during various forms of exercise. The studies reviewed in this section generally fall under one of three categories. They examined the effect of CrH₂O supplementation on either (a) a single bout or (b) repeated bouts of HI-ST exercise or (c) supplementation in
conjunction with a training program designed to enhance performance over a period of time.

### 2.5.1 Single Bout Exercise Performance and Creatine Supplementation

Investigations by Dawson et al. (1995), Mujika et al. (1996), Odland et al. (1997), Redondo et al. (1996), and Terrillion et al. (1997) have examined whether or not Cr.H2O may enhance performance during a single maximal bout of short-term exercise. These studies used a variety of high intensity exercise protocols including 60 meter running sprints, 700 meter running sprints, 25, 50 and 100 meter swim sprints, and 10 second cycle sprints. Each of these studies reported that supplementation does not provide any positive ergogenic effect for these types of activities. The supplementation protocol for these studies followed the same guidelines established by Harris et al. (1992). Only one of these groups of researchers directly measured Cr levels following supplementation to assess the effect on intramuscular TCr levels. Odland et al. (1997) reported significant increases in TCr and minor non-significant increases in PCr. This is in agreement with Harris et al. (1992) and Hultman et al. (1996) who found TCr increased in all subjects, due mainly to an increase in Crf, following the standardized Cr.H2O loading protocol.

Using the 30 second Wingate protocol, Jacobs et al. (1997) are the only researchers (to date) to have demonstrated an improvement in a single bout of high intensity short term exercise following Cr.H2O supplementation. Administering the standard loading regime to 14 subjects, they reported that time to exhaustion (TE) increased significantly following supplementation.

It has been clearly demonstrated that Cr.H2O supplementation can significantly increase intramuscular TCr stores. However, few researchers have observed a significant increase in PCr levels following supplementation. Augmented intramuscular Cr following supplementation is largely in the form of Crf. This may not provide a direct/immediate benefit to HI-ST performance, but may provide an advantage during repeated bouts of activity or as in the case of Jacobs et al. (1997), during single bouts of HI-ST activity to
complete exhaustion. It has been suggested that improved performance following Cr supplementation is related to the ability of Cr, in its PCr form to act as a proton buffer (Volek and Kraemer, 1996). During HI-ST exercise lasting less than 2-3 minutes, protons are generated during lactate formation. When PCr is used to resynthesize ATP in the creatine kinase reaction, $H^+$ ions are consumed, thus attenuating the acidosis accompanying rapid lactate formation. This helps to maintain a normal pH inside the muscle and during maximal exercise reduces the rate at which muscle pH is lowered. A drop in pH directly effects energy metabolism during HI-ST activity by either altering the structure of the enzyme(s) required by the specific energy system(s) or by affecting the energy substrate for the particular enzyme(s).

2.5.2 Repeated Bout Exercise Performance and Creatine Supplementation

Several investigators have found an increase in performance during repeated bouts of HI-ST activity following Cr.$H_2O$ supplementation (Balsom et al., 1993a; Balsom et al., 1995; Birch et al., 1994; Earnest et al., 1995; Greenhaff et al., 1993; Volek et al., 1997). A few have reported conflicting results (Barnett et al., 1996; Cooke and Barnes, 1997; Febbraio et al., 1995). Each of these studies followed the guidelines for supplementation initially described by Harris et al. (1992) and used a placebo group for comparisons. While TCr content was not directly measured in all of these investigations it is likely that the Cr.$H_2O$ supplementation resulted in a significant increase in intramuscular TCr following the loading phase (Harris et al., 1992).

Balsom et al. (1993b) used ten, 6 second bouts of high intensity cycling with 30 seconds rest between each bout. Performance was enhanced in the Cr compared to the placebo group and they postulated the improved performance was due to a higher initial PCr availability and an increase in the rate of PCr resynthesis during recovery. Also, post exercise plasma ammonia and hypoxanthine concentrations were lower in the Cr group suggesting a lower degradation of the total adenine nucleotide pool and better maintenance
of the ATP:ADP ratio via a more rapid rate of ATP resynthesis. Greenhaff et al. (1993) using 5 x 30 maximal voluntary isokinetic contractions separated by one minute recovery periods and Birch and Greenhaff (1994) using repeated 3 x 30 second Wingate tests with four minutes recovery between each, reported similar findings and offered the same mechanisms as Balsom et al. (1993) for the increases measured. All three research teams reported lower levels of plasma hypoxanthine in their respective Cr groups following exercise.

Earnest et al. (1995) did not measure plasma concentrations of ammonia or hypoxanthine. However, Cr.H$_2$O supplementation did result in significant improvements in total work for three consecutive 30-second Wingate tests separated by five minutes of rest. Balsom et al. (1995) observed that following supplementation subjects were better able to maintain power output during a final 10 second maximal bicycle sprint preceded by five, 6 second bike sprints with 30 seconds rest between each. Finally, Volek et al. used a resistance exercise protocol and found Cr.H$_2$O supplementation enhanced bench press and jump squat repetitions to failure using a predetermined 10 RM load over five repeated bouts for each exercise (on separate days) with 2 minutes recovery between bouts.

All of the various exercise protocols utilized by these investigators shared two common denominators. First, the work to rest ratios were such that it is likely a significant amount of PCr resynthesis was allowed to occur before the next bout of activity. PCr levels are replenished quite rapidly in the muscle following maximal exercise. Within one minute approximately 50% of the pre-exercise PCr content is restored and within 5 minutes total PCr resynthesis is complete (Balsom et al., 1994). The rate of resynthesis is dependent on the level and intensity of activity and as mentioned it may be dependent on the pre-exercise level of TCr/PCr in the muscle. Secondly, for each of these methodologies subjects performed at least three consecutive bouts of exercise.

In conflict with these results are the reports by Febbraio et al. (1995), Barnett et al. (1996) and Cooke and Barnes (1997) who measured performance during a 4 x 40 second maximal cycle sprints interspersed with one minute of recovery, a 2 x 4-7 second maximal
sprints with either 30, 60, 90 or 120 seconds recovery and a 7 x 10 second cycle sprint protocol with 30 seconds recovery, respectively. None of these reports provided support for a positive ergogenic effect of Cr.H$_2$O on performance, plasma ammonia or blood lactate levels compared to placebo. However, the specific exercise regime used in the investigations by Febbraio et al. and Cook and Barnes while classified as HI-ST activities can not be considered the same as those outlined previously in the studies supporting Cr.H$_2$O as an ergogenic substance.

The two common denominators listed for the supporting literature are non-existent in these two investigations. Of notable difference were the recovery times between each successive bout of activity for both protocols. These likely were insufficient to allow significant replenishment of PCr. Also, both of these studies examined the effect of supplementation on performance for only two repeated bouts of HI-ST activity. While these investigations incorporated a "HI-ST exercise protocol" it is obvious there are important differences between these protocol and those used by Balsom et al. (1993), Balsom et al. (1995), Greenhaff et al. (1993), Birch and Greenhaff (1994), Earnest et al. (1995), and Volek et al. (1997). Of interest is the study by Barnett et al. (1996). In this study both common denominators were present (7 x 10 second sprints x 2-5 minutes recovery) yet no difference in pre or post performance or plasma lactate and blood pH measurements were found between the Cr and P groups. The authors stressed that since they did not directly measure pre or post-supplementation TCr levels it is possible that the supplementation protocol failed to significantly raise intramuscular TCr levels. This is supported by their observation that subjects receiving Cr.H$_2$O did not experience a significant weight gain following the supplementation period. In each of the investigations listed previously, regardless of the effect that Cr. H$_2$O had on performance, subjects receiving the standardized Cr.H$_2$O loading supplementation all experienced a significant weight gain averaging 1.0 kg. There is considerable controversy over what this short term weight gain constitutes but it likely results from an increase in intramuscular water retention. This hypothesis has yet to be
Regardless of the mechanism(s) involved, rapid weight gain is a consistent observation following the described supplementation protocol and can be considered an indirect method for determining whether an increase in creatine retention in the muscle has occurred. This does not negate the findings of Barnett et al. (1997) However, it does support the explanation that for their subjects the supplementation period may not have significantly increased resting TCr levels.

While the results of these investigations appear contradictory it is obvious the term high intensity short term (HI-ST) exercise must be more clearly defined in order to gain a better understanding of how and where Cr.H₂O supplementation may benefit performance.

2.6 Creatine Supplementation and Training

Several investigators have examined the hypothesis that Cr.H₂O could provide an ergogenic benefit during single or repeated bouts of HI-ST activity. In the previous sections a majority of these investigations were outlined and the results, while not conclusive certainly warrant continued research. While short-term Cr.H₂O supplementation may provide an immediate benefit during the type of activities and exercise protocols described in the previous section, in practice this is not how and where this substance is primarily being used.

Since the original work by Harris et al. (1992) thousands of individuals in North America and abroad regularly supplement Cr as part of their total training regime. Its use is so rampant among both recreational and top amateur and professional athletes from a variety of sports that it has quickly become the number one selling supplement on the market today with literally dozens of suppliers vying for a share of the market and sales expected to reach over 200 million dollars in 1998 (Schnirring, 1998). The ergogenic benefit for which it is being taken is not related to short term enhancement of performance during single/multiple bouts of HI-ST activity per se, but for its supposed enhancement on muscle strength and muscle mass in conjunction with a long-term high intensity resistance training program.
Only a handful of researchers have examined the benefits associated with extended Cr.H₂O supplementation in conjunction with resistance training.

Vandenberghe et al. (1997) examined the effects of extended oral Cr.H₂O supplementation in combination with ten weeks of resistance training on muscle strength and body composition in 19 healthy, sedentary females aged 19-22 years. In ten subjects, Cr.H₂O was loaded for the first 4 days at a dosage of 20 grams per day (4 x 5 gram servings). This was followed by a 5 gram serving once per day for the remainder of the ten week period. The other nine subjects received a placebo following the same dosage procedure. They reported that, compared with the placebo, muscle strength increased 20-25% and fat free mass increased 60% more during Cr.H₂O supplementation. These results are significant in that they are the first controlled investigation to show a long-term benefit from Cr.H₂O supplementation on strength following a standardized resistance training program. They are not however, the first to report enhanced strength and/or fat free mass following supplementation. Sipila et al. (1981) studied the effects of one year of Cr supplementation (1.5 grams/day) as treatment for gyrate atrophy of the choroid and retina, a disease characterized by marked progressive atrophy of Type II (T-II) skeletal muscle fibers. They reported one year of this treatment resulted in a significant increase in body weight and increased diameter of T-II fibers in all patients. Kreider et al. (1996) reported that, compared to placebo, Cr.H₂O supplementation for 28 days significantly increased lean body mass (excluding bone) as measured by dual energy x-ray absorbitometry. The subjects were strength trained males below 40 years of age who were likely performing resistance training but did not follow any standardized training program during the supplementation period. No strength measures were taken.

Earnest et al. (1995) compared 28 days of placebo or Cr.H₂O ingestion on strength and body composition in 10 experienced male weight trainers. It is not known whether they were involved in a resistance training program during the 28 day intervention period, but they did not follow a standardized training program. Regardless, those subjects receiving
Cr.H₂O demonstrated significant increases in 1 RM bench press (+6%), total lifting volume (+29%) and body weight (+1.7kg).

While only one of the above training studies actually examined the effects of Cr.H₂O ingestion during prolonged resistance training, together they provide initial support for the already standard practice of taking oral Cr.H₂O in order to enhance muscle strength and muscle hypertrophy specifically in association with resistance training.

In another study, not involving exercise training, Tarnopolsky et al. (1997) investigated the effects of Cr.H₂O treatment on patients with mitochondrial cytopathies. This disease results in fatigue related to decreased basal and post-activity PCr levels. After three weeks of either placebo or Cr.H₂O supplementation (10 grams/day for two weeks and 4 grams/day for one week), significant increases in high intensity anaerobic strength measures including ischemic isometric hand grip strength were noted for the creatine supplemented group. No changes were observed in the placebo group.

Of all the forms of HI-ST exercise studied thus far, it appears in terms of consistent results that a regime of Cr.H₂O supplementation coupled with high intensity resistance training may provide the greatest ergogenic benefit. Improvements in strength and body mass observed under this regime are likely due to one or a combination of the following mechanisms:

1. Supplementation may increase the ability to perform a higher total training workload in a given period of time. Vandenberghhe et al. (1997) reported that during the second half of their ten week resistance training program subjects receiving Cr.H₂O supplementation were training at a higher absolute training intensity than those receiving the placebo. After the first five weeks of training, workloads were adjusted to reflect the new 1 RM for each subject. This new 1 RM was significantly higher for all subjects in the Cr.H₂O group. Thus, the adjusted training loads for these subjects were greater which means the total training workload for the last five weeks of the study were also higher for these subjects.
2. Supplementation may increase the ability to maintain optimal training for a longer period of time before overtraining develops. Vandenberghe et al. (1997) also reported the maximal intermittent exercise capacity of the arm flexors deteriorated during the final five weeks of their ten-week protocol in subjects receiving the placebo only. This may indicate some degree of overtraining which negatively effects performance (McArdle et al. 1986).

3. Supplementation may enhance protein synthesis in skeletal muscle. Numerous studies have reported a significant increase in body mass following creatine supplementation (Balsom et al., 1993a; Balsom et al., 1995; Cooke & Barnes, 1997; Earnest et al., 1995; Kreider et al., 1996; Volek et al., 1997). These investigations measured only body weight, fat free or fat free/bone free - body mass. To date only one investigation has actually measured morphological changes in the muscle in response to oral Cr supplementation. The study by Sipila et al. (1981) observed that one year of daily low dosage Cr resulted in significant increases in the cross-sectional area of T-II muscle fibers only. The body mass changes consistently reported following Cr ingestion are attributed either to an increase in intramuscular water retention or an actual increase in muscle protein synthesis. For the majority of these studies water retention is likely accountable since supplementation periods were less than 14 days. This does not rule out the possibility that muscle protein synthesis may be enhanced.

As mentioned, the studies by Vandenberghe et al. and Sipila et al. monitored changes over a ten week and one year period respectively, and the Vandenberghe et al. study incorporated high intensity resistance training. Thus, it is possible the observed changes in these two investigations were due to increased muscle hypertrophy. Two proposed mechanisms for this are (1) the higher training intensities and volumes reported following Cr.H2O supplementation, and their effect on protein synthesis over time and/or (2) a direct effect of creatine on muscle-specific protein synthesis (Bessmen and Savabi, 1988, Hoffman et al., 1978; Ingwall, 1976).
2.7 Side Effects

There were no reports of potential harmful side effects associated with Cr.H$_2$O supplementation in any of the investigations outlined in this review. Since Cr.H$_2$O supplementation has been examined in only a few long term investigations there is some concern that we do not yet know the implications of long term Cr.H$_2$O use. However, the recent ten week study by Vandenberghe et al. (1997) reported that none of their subjects experienced any negative effects as a result of supplementation. The study by Sipila et al. (1981) studied the effects of low dosage Cr.H$_2$O supplementation over a one year period and not only reported no negative side effects as a result but that Cr was an effective treatment for the specific ocular impairment studied.

In a recent investigation by Poortmans et al. (1997) the authors outlined the concern that a nitrogen rich diet may contribute to a functional and structural deterioration of the kidney and that the two amino and one carboxyl groups and the high nitrogen content of Cr could place a greater than average strain on the kidney if larger dosages were ingested than are generally obtained in the diet. However, after Cr.H$_2$O was taken orally for five days at the dosage of 20 grams per day in a group of males ~ 25 years of age it was concluded that this Cr.H$_2$O supplementation regime did not appear to have any detrimental effect on the renal response of the men involved.

2.8 Summary

Based on the information presented in this literature review it can be concluded that:

1. Oral supplementation with creatine for 4-7 days at a dosage of 20 grams per day in 4 servings of 5 grams each, can significantly increase the TCr pool in the muscle.

2. The increase in TCr is due to an increase in both PCr and Crf, with Crf accounting for at least 60% of the increase.
3. Following the Cr.H₂O loading phase, peak intramuscular TCr can be maintained via a maintenance dosage of 2-5 grams per day for a period of at least 10 weeks.

4. Cr retention following supplementation is highest in those individuals who demonstrate the lowest initial TCr levels.

5. Cr retention is higher in the muscle when supplementation includes simultaneous ingestion of simple carbohydrates.

6. Cr retention in the muscle is higher when supplementation is combined with intense exercise.

7. Cr supplementation may enhance performance during repeated bouts of HI-ST exercise, but probably not during a single bout of HI-ST exercise.

8. Cr supplementation in conjunction with high intensity resistance training may increase strength and muscle hypertrophy to a higher level than would be expected with resistance training alone. Possible explanations for this ergogenic effect include; higher training loads, reduced training fatigue and possibly increased protein synthesis.

9. Deleterious effects of short-term oral creatine supplementation have not been identified. Harmful effects associated with prolonged oral Cr.H₂O supplementation have not been adequately studied.
3.0 Methodology

3.1 Experimental Design

The following experimental design and specific testing protocol were applied to investigate both (a) the immediate, short term effects on strength and functional performance of the oral Cr.H₂O loading phase and (b) the long term effects of the Cr.H₂O loading and maintenance phases, when combined with resistance training. Therefore, this study incorporated two separate designs, both of which followed a randomized, double blind protocol (see Table 1: Study Design).

The first part of the design was a 2 x 3 factorial design with repeated measures on the second factor. Factor 1 was GROUP (either treatment [Cr] or placebo [P]) and factor 2 was TIME (T1-baseline, T2-after the first week of training and supplementation, T3-post testing). Pre (T1), Mid (T2) and Post (T3) testing measurements for body weight (WT) and repetitions to failure for the chest press using the baseline 10 RM weight established at T1 (REPS) were recorded for each level of TIME. Comparison of data from T1 to T2 for WT and REPS provided an indication of the degree to which supplementation had an immediate effect on performance.

The second part of the design examined the effects of extended supplementation in combination with resistance training and incorporated a 2 x 2 factorial design with repeated measures on the second factor. Factor 1 was GROUP (Cr or P) and factor 2 was TIME (T1,
T3). Pre (T1) and post (T3) test measurements were recorded for hand grip strength (GRIP), modified chair rise (CR), medicine ball lift (MB), and 10 RM chest press (CP) - seated row (SR) - leg curl (LC) - leg extension (LE). 10 RM tests were chosen as they are considered a standard test for muscular strength and are a more reliable test to administer than a one RM test which also places the subject at a higher risk of injury (McArdle et al. 1986). All testing was conducted at the Executive BirdCoop Fitness Center at the University of British Columbia.

Table 1: Study Design

<table>
<thead>
<tr>
<th>FACTOR ONE</th>
<th>FACTOR TWO (TIME)</th>
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<tbody>
<tr>
<td></td>
<td>T1</td>
</tr>
<tr>
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<td>WT, REPS,</td>
</tr>
<tr>
<td>(n=26)</td>
<td>GRIP, CR,</td>
</tr>
<tr>
<td></td>
<td>MB, CP, LC, SR,</td>
</tr>
<tr>
<td></td>
<td>LE,</td>
</tr>
<tr>
<td>CREATINE</td>
<td>WT, REPS,</td>
</tr>
<tr>
<td>(n=27)</td>
<td>GRIP, CR,</td>
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<tr>
<td></td>
<td>MB, CP, LC, SR,</td>
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3.2 Subjects

A total of 58 subjects between the ages 50 - 75 years volunteered to participate in this study after being fully informed of the procedures and their risks and signing an approved
ethical consent form. The subjects (men, n=26 and women, n=27) were selected from The University of British Columbia Changing Aging Adult Fitness Program and through an add placed in a local newspaper. Recruitment included information sessions held during Changing Aging class times and information bulletins posted at the Executive BirdCoop Fitness Center where the Changing Aging Program takes place. Inclusion criteria for participation in this study included: a) involvement in the Changing Aging program, b) between the ages 50 and 75 years inclusive, c) informed consent and d) medical clearance to participate in the exercise program. Exclusion criteria included: a) recent musculoskeletal injury, b) major surgery in the past six months, c) arthritis to the extent that limited activity, d) confirmed diagnosis as hypertensive and/or currently taking medication for hypertension without prior medical clearance, e) failure to obtain medical clearance, f) failure to complete informed consent, g) inability to attend only one of the three supervised training sessions per week for the entire six week treatment period, h) missing more than two scheduled training sessions within the six week period and i) ingestion of oral creatine monohydrate during the three months prior to initiation of the treatment period.

3.3 Experimental Period

The total duration of the study period was eight weeks. Included in this time period was one week of initial orientation and testing (T1) followed by six weeks of training/supplementation and ending with the final week of testing (T3). A six week training period was chosen as it is the minimum amount of time required to provide for both the initial neural adaptation period (approximately 2 weeks) followed by a minimum period to
show a training response (Bompa, 1983). At the beginning of the second week of the six week intervention period (actually Week 3) measurements for body weight and repetitions to failure using the same 10 RM weight established one week earlier for the CP test only, were taken. Each week began on the Monday and ended on the following Sunday. Throughout the eight week period subjects were asked to maintain their normal diet and activity patterns. Food intake and recreational activities were not controlled. However, subjects were asked to refrain from any form of resistance training outside of the prescribed six-week resistance training program. Before any testing was initiated, subjects completed a brief questionnaire to determine their typical intake of meat, fish, and poultry and their present level of training.

Random, stratified sampling was used to assign subjects to either the Cr or P groups. This was based on three factors for each subject, age, sex and activity level. Once subjects were classified according to the numbered categories for each factor they were randomly assigned to either the Cr, who received oral, powdered creatine monohydrate supplementation or the P who received an oral inactive substance (glucose). Age was broken into 5 categories: [50-54; (Cr n =6, Pl n=6), 55-59 (Cr n=5, Pl n=6), 60-64 (Cr n=7, Pl n=8), 65-69 (Cr n=5, Pl n=4), 70-75 (Cr n=4, Pl n=2); sex into two: male (Cr n=13, Pl n=13) or female (Cr n=14, Pl n=13); and activity level into three: [1] no resistance training experience (Cr n=15, Pl n=14), [2] 0-3 months resistance training experience (Cr n=8, Pl n=8) and [3] greater than three months resistance training experience (Cr n=4, Pl n=4).

Independent t-tests confirmed that the final randomly selected Cr and P groups did not differ significantly (all p’s > 0.50) from each other on these three variables (see Appendix A).

The six week intervention period involved three non-consecutive, instructor-led
training sessions per week. Each session consisted of a five minute warm-up followed by 35-40 minutes of resistance training involving eight exercises targeting the major muscle groups of the body and completed with a five minute stretch/cooldown. A list and description of these exercises is provided in Appendix B. The resistance training portion of the program incorporated a six week step-progression overload plan (Bompa, 1983) which involved the following progression for sets and repetitions for each exercise: first two weeks, three sets of 12 repetitions with 60 seconds rest between each set and exercise (3 x 12 x 60); second two weeks, 3 sets of 10 repetitions with 90 seconds rest between each set and exercise (3 x 10 x 90); and final two weeks, 3 sets of 8 repetitions with 120 seconds rest (3 x 8 x 120).

Whenever a subject could perform all three sets of an exercise for the prescribed number of repetitions within the allotted rest times on their own, he/she was instructed to increase the resistance by 5-10 pounds. For each progression to the next two week schedule, with fewer repetitions per set, the load was increased by ten percent for the first session at the new range. This was designed to maximize strength gains in this period of time. Each subject maintained their own personal daily training log which was reviewed weekly by the researcher to ensure the above progressions took place.

Several instructor-led sessions were scheduled each week for the entire six-week period. Each subject was required to attend at least one of these instructor-led sessions per week for the duration of the study. Subjects were permitted no more than two sessions per week of training on their own. All subjects were strongly encouraged to schedule every training session during the instructor-led times. Compliance was assured via daily sign-in sheets for each workout session.
3.4 Time-course

Week 1

An initial orientation session was held to explain all aspects of the research study and subjects were familiarized with what was expected of them during all testing and training sessions. All baseline testing (T1) was completed during this first week for each subject. Based on their 1 RM testing the initial workload was determined for each exercise for the upcoming resistance training program. Subjects were given their supplementation package which included the entire amount of their prescribed supplement (Cr.H₂O or P) for the six week intervention period. Each subject was clearly shown how to self-administer the supplement and an information sheet outlining all the supplementation and training protocols for the entire six week period was provided.

Week 2

Subjects began the supplementation period and resistance training program. Supplementation for the first week was as follows: The seven days of Week 1 constituted the loading phase where all subjects (Cr and P) orally self administered four, 5 gram servings per day of their prescribed supplement at 2-3 hour intervals (20 grams/ day). They were instructed to thoroughly mix the supplement before ingestion, using either water, juice, or tea but not coffee, milk, or any type of alcoholic beverage. On the Monday, subjects began the six week, three session per week resistance training program starting with the 3 x 12 x 60 range.

Week 3

Subjects were re-tested for WT and REPS prior to the start of their first scheduled
training session this week. They continued with the 3 x 12 x 60 range. Supplementation changed to a maintenance dosage of one 5 gram serving per day administered in the same manner for both Cr and P. To maintain consistency subjects were asked to ingest this single dosage at approximately noon during non-training days and approximately two hours before their exercise session on training days. This maintenance dosage continued for the duration of the intervention period.

**Week 4**

Subjects progressed to the 3 x 10 x 90 exercise range. Maintenance supplementation continued.

**Week 5**

Same as Week 4.

**Week 6**

Subjects progressed to the 3 x 8 x 120 range and maintenance supplementation continued.

**Week 7**

Same as Week 6.

**Week 8**

Subjects stopped both supplementation (Cr and P) and the resistance training program at the end of Week 7. They were encouraged to maintain the other parts of the exercise session (stretching and cardio-respiratory), but were asked to refrain from any form of resistance training until their final testing session (T3) had been completed. T3 took place during Week 8 and all subjects were re-tested on all tests.
3.5 Materials

Equipment required for measurement in this study included a TAKEI hand grip dynamometer, an electronically calibrated anthropometric weigh scale, three medicine balls (2.2, 4.4 and 6.5 kg), a 50 cm high bench, 150 cm shelf, a standard height chair (0.43 m), stop watch, and Keiser air powered exercise devices to measure seated bench press, seated row, seated hamstring curl, and seated leg extension performance. Equipment used in this study excluding the hand grip dynamometer provided direct measurement for their respective variables. Therefore, for these tests there are no assumptions about how the units measured relate to the variable being assessed. Hand grip strength is considered, in general to be a reliable indicator of overall body strength (McArdle et al, 1986). However, it really only measures strength of the forearm and hand flexors. Therefore, its generalizability to other muscle groups may not be truly reflective of the strength capacity of these muscle groups.

3.6 Procedures

All testing sessions took place in the Executive BirdCoop Fitness Center. The dependent variables WT, GRIP, CR, MB, SR, CP, LC, LE and REPS were measured by the author. For variables WT and REPS subjects were tested on three separate occasions (T1, T2, T3) while variables GRIP, CR, MB, SR, CP, LC and LE were measured on two (T1, T3). During the initial testing (T1) session each subject underwent an orientation to learn the proper protocol for each test. They were asked not to attempt or practice any of the tests following T1. Prior to the initiation of any testing procedures eight individuals (50-70 years of age) who were not part of the training study, were involved in a test, re-test reliability
session for all protocols (excluding 10 RM tests) to determine: a) the number of trials
required for each test to ensure proper measurement, b) the number of trials for each test
before a learning effect was noticed in the measurement and c) to determine whether
accepted protocol for standardized tests (WT and GRIP) were in fact the most effective
procedure for this group of subjects. Based on this reliability testing and on standardized
testing protocol the following procedures were identified and followed for each particular
test (results from the statistical analysis of the reliability testing is provided in Appendix C).
The following are descriptions for dependent variable measurement procedures.

3.6.1 Body Weight (WT)

Body weight was measured at the start of each testing session and each testing
session was conducted at approximately the same time of day for each subject. Subjects
were required to wear a pair of light shorts, T-shirt and socks or stockings and to void their
bladders. WT was measured once for each subject and was recorded in kilograms to the
nearest 100 grams.

3.6.2 Grip Strength (GRIP)

For hand grip strength subjects were asked to stand with feet shoulder width apart.
They were asked to grasp the dynamometer in one hand with the dial facing away from
them. The grip was taken between the fingers and the palm at the base of the thumb. The
grip of the dynamometer was adjusted so the second joint of the fingers fit snugly under the
handle and took the weight of the instrument. Once adjusted the grip was locked in place and
the dial set to the "0" kilogram mark. The grip setting was recorded and all subsequent tests were performed at the same individual setting for each subject. The subject was then instructed to hold the dynamometer in line with the forearm (elbow straight) at the level of the thigh. On the tester's command the subject squeezed the handle as hard as possible for approximately 3-5 seconds. The tester ensured that all subjects exhaled while squeezing to avoid build-up of intra-thoracic pressure which might have caused dizziness. Subjects were not allowed to touch the dynamometer or the arm on the side being tested with any object or part of the body while squeezing. Two measurements were taken for each hand and the highest score rounded to the nearest kilogram was recorded as the final score for each hand. The score for each hand was then summed to provide a single score for GRIP.

3.6.3 10 RM Strength Tests

Ten RM strength for the SR, CP, LC, and LE were measured using the Keiser air-powered Seated Low-Row, Seated Chest Press, Seated Hamstring Curl, and Seated Leg Extension resistance machines (respectively). All subjects were lead through an appropriate warm-up prior to maximal testing. Initially the weight for each test was set to 20 LB for females and 40 LB for males. If they successfully completed the first 10 RM test they were given a two minute rest. The weight was then increased by a safe amount which was determined by the tester who was a Certified Strength and Conditioning Specialist (on average 5-20 pounds for females and 20 - 50 pounds for males) and the test repeated. This procedure continued until the subject reached a weight that he/she could not perform for ten repetitions using the proper protocol for each test or when he/she or the tester felt that they
could not lift the next weight increment safely. The ten RM maximum for all tests was achieved within three test trials for each subject. After the initial test, if the second selected weight was determined to be too light by the tester the test was terminated prior to completion of the ten repetitions and the subject allowed to rest the same two minutes before trying again at a heavier weight. This ensured that the subject did not fatigue prior to achieving a true 10 RM by performing numerous submaximal sets of 10 repetitions. The final maximal weight lifted for ten complete repetitions was recorded as the 10 RM for that test. Cadence for each repetition was counted for the negative phase of the motion only where subjects returned to the starting position on a two second count. The procedure for determining a 10 RM was uniform for the SR, CP, LC, and LE tests. Together the scores from these four tests provide an indication of whole body strength change. Thus, for statistical analyses and discussion purposes they will be combined to form a STRENGTH construct. Specific descriptions for each of the four 10 RM tests is provided in Appendix D.

3.6.4 Functional Tests

The two functional tests performed, the modified Chair Rise and Medicine Ball Lift were used as indices of functional ability for the lower and upper body respectively. The scores from these two tests were combined to form the construct FUNCTION for statistical analyses and discussion purposes. The following is a detailed description of each individual functional test.

Chair Rise (CR)

For the CR subjects sat in a standard height chair (0.43 m high) with their feet flat on
the ground, knees bent at 90°, low back firmly against the seat back and their arms crossed in front of the chest. The test required the subject to stand up from the seated position and return to sitting ten times without the use of the arms. The arms remained crossed in front of the body. Each time the subject sat down their back firmly touched the seat back before they rose again. Upon rising they stood erect with their back, hips and knees fully extended (but not hyperextended). Each subject was given one trial of this test and the time taken to complete all ten repetitions recorded as their score. Recording started on the first movement for the first chair rise and stopped when the subject had completed the tenth rise and was seated with his/her back flat against the seat back. Subjects were instructed not to bounce off the chair back but to make soft contact before re-standing. Subjects were given one 5 repetition un-timed, warm-up trial before completing the ten repetition test. Time was recorded to the nearest hundredth of a second.

**Medicine Ball Lift (MB)**

The MB test incorporates both upper and lower body strength and power. For this test subjects were required to lift a series of three medicine balls weighing 2.2, 4.4 and 6.5 kg (from heaviest to lightest) off a 0.50 m high x 60” long bench and place each medicine ball into a 20”x 20” cubby hole located directly in front of and above each ball on top of a 1.50 m high shelf located directly behind the bench. They then immediately removed the medicine balls from the high shelf one at a time in succession from lightest to heaviest, back down onto the low bench. All subjects were instructed on proper lifting form to ensure excess strain was not placed on the lower back. Subjects started by standing tall in front of and at the left end of the low bench directly in front of the 6.5 kg medicine ball with their toes
touching the base of the bench and their hands gripped behind their back. The balls were spaced equally apart from each other, down the length of the bench with the smallest ball at the far right. These positions paralleled the positions of the three cubby-holes located directly in front and above. Timing started at the subjects first hand movement and continued until all the medicine balls had been placed onto the high shelf then back onto the low bench in the manner just described and stopped when the subject finished with their hands clasped behind their back in the standing position at the original starting point. Each subject was given two trials of this test with 2 minutes of rest in between each trial. The first trial was a non-timed warm-up followed by the timed test. Time was recorded to the nearest one hundredth of a second.

3.6.5 Repetitions to Failure Test

The repetitions to failure test involved the same protocol for the CP test. A complete description of the protocol for this procedure is provided in Appendix D.

3.7 Statistical Analysis

The effect of Cr.H₂O supplementation versus placebo administration was tested using a Group x Time ANOVA design and a Group x Time MANOVA design both with repeated measures on the time factor. Specifically, the following 5 separate analyses were performed: (1) a 2 x 3 ANOVA design to test for significance between T1, T2, and T3 for the dependent variable WT; (2) a 2 x 3 ANOVA design to test for significance between T1, T2, and T3 for the dependent variable REPS; (3) a 2 x 2 ANOVA design to test for
significance between T1 and T3 for the dependent variable GRIP; (4) a 2 x 2 MANOVA design to test for significance between T1 and T3 for the construct STRENGTH which consisted of the dependent variables CP, SR, LC and LE; (5) and finally a 2 x 2 MANOVA design to test for significance between T1 and T3 for the construct FUNCTIONAL ABILITY which consisted of the dependent variables MB and CR. Significance for all ANOVA and MANOVA analyses was set at $\alpha=0.05$. All data reported in tables are expressed as means +/- standard deviations.
4.0 RESULTS

4.1 Introduction

The effects of Cr.H_{2}O supplementation in conjunction with high-intensity resistance training on strength and functional abilities of adults aged 50-75 years was assessed on a sample of 53 subjects. Subjects were assigned to one of two treatment groups, Creatine (Cr) or Placebo (P). Analysis of results was separated into two main parts. The first part explored the short term effects of seven days of creatine loading and resistance training on the dependent variables body weight (WT) and repetitions to failure for the chest press exercise (REPS). The second part examined longer term effects of creatine loading plus maintenance combined with six weeks of resistance training on the dependent variables WT, REPS, grip strength (GRIP), 10 RM seated chest press (CP), seated row (SR), leg extension (LE), leg curl (LC) and two functional tests - the modified chair rise (CR) and medicine ball lift (MB).

Analyses of the data indicates the initial hypothesis, which stated the Cr group would significantly outperform the Pl group on all dependent measures and show a significant increase in body weight following supplementation and resistance training, was not supported by the results of this investigation. Specifically, the results of this chapter will elucidate on the following individual hypothesis conclusions;

1. Gain in body weight (WT) at T2 and T3; \( \text{CR} = \text{PL}* \)

2. Improvement in repetitions to failure (REPS) at T2 and T3; \( \text{CR} = \text{PL}* \)
3. Improvement in grip strength (GRIP) from T1 to T3; \( \text{CR} = \text{PL}^* \)

4. Improvement in time for functional tests (FUNCTION) from T1 to T3; \( \text{CR} = \text{PL}^* \)

5. Increase in whole body strength (STRENGTH) from T1 to T3; \( \text{CR} = \text{PL}^* \)

6. All Subjects improved on all dependent variables regardless of treatment group.

\( * \alpha \) set at 0.05

4.2 Subjects

58 subjects volunteered to take part in this investigation. All were pre-tested at T1 on the dependent variables (WT), (GRIP), CR, MB, CP, SR, LC, LE, and REPS. Following the second week of training one male subject from the placebo group voluntarily withdrew from the study due to aggravation of an existing injury. Four other subjects (two females from each of the placebo and experimental groups) completed all baseline (T1), mid (T2) and post (T3) testing but were excluded from all statistical analyses due to a lack of compliance with experimental protocol for the six week resistance training program. The remaining 53 subjects maintained the criteria for compliance (inclusion/exclusion criteria) as outlined in Chapter 3. Table 2 summarizes subject data for all subjects, (males and females) and for the Cr and P groups at the beginning of the study. All values are expressed as means with standard deviations in parentheses.
Table 2: Subject Data; Means for Age, Sex, Body Weight and Activity Level

<table>
<thead>
<tr>
<th>GROUP</th>
<th>N</th>
<th>AGE (Years)</th>
<th>WEIGHT (kg)</th>
<th>SEX (1=male, 2=female)</th>
<th>ACTIVITY LEVEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. All Subjects</td>
<td>53</td>
<td>60.28 (6.90)</td>
<td>75.99 (14.59)</td>
<td>1.51 (0.51)</td>
<td>1.60 (0.74)</td>
</tr>
<tr>
<td>2. Males Only</td>
<td>26</td>
<td>61.46 (7.39)</td>
<td>83.99 (13.56)</td>
<td>1</td>
<td>1.62 (0.80)</td>
</tr>
<tr>
<td>3. Females Only</td>
<td>27</td>
<td>59.15 (6.32)</td>
<td>68.28 (11.08)</td>
<td>2</td>
<td>1.59 (0.69)</td>
</tr>
<tr>
<td>4. Creatine Group</td>
<td>27</td>
<td>60.85 (6.64)</td>
<td>74.57 (15.54)</td>
<td>1.52 (0.51)</td>
<td>1.59 (0.75)</td>
</tr>
<tr>
<td>(m=13) (f=14)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1=15 subjects</td>
</tr>
<tr>
<td>5. Placebo Group</td>
<td>26</td>
<td>59.69 (7.24)</td>
<td>77.45 (13.67)</td>
<td>1.50 (0.51)</td>
<td>1.62 (0.75)</td>
</tr>
<tr>
<td>(m=13) (f=13)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1=14 subjects</td>
</tr>
</tbody>
</table>

*Activity Level was classified as either 1, 2 or 3 according to the following categorization: 1 = no resistance training experience; 2 = 0-3 months resistance training experience; 3 = more than three months resistance training experience.

4.3 Body Weight (WT)

Table 3 displays the mean body weights recorded at time trials T1, T2 and T3 for the Cr and P groups. A 2 x 3 ANOVA analysis revealed.

(a) a non-significant GROUP x TRIAL interaction effect for the dependent variable WT between the Cr and P groups across time trials T1, T2 and T3 (p=0.204), and a non-significant TRIAL main effect (p=0.14).

Visual inspection of the data in Table 3 shows the change in WT between T1 and T2 for Cr was apparently greater than for P (0.77 kg vs 0.20 kg, respectively) for the subjects in
this sample. Since consequential issues concerning the effect of supplementation on WT during the early stages of the six week intervention are relevant to this study it is important to note this difference even though statistical significance was not obtained. To summarize, WT did not deviate significantly from baseline (T1) throughout the six week period for either the Cr or P groups.

Table 3: Mean Values for Body Weight at T1, T2, and T3)

<table>
<thead>
<tr>
<th>GROUP</th>
<th>TEST TRIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T1</td>
</tr>
<tr>
<td>1. Creatine Group</td>
<td>74.57 (+/- 15.53)</td>
</tr>
<tr>
<td>2. Placebo Group</td>
<td>77.45 (+/- 13.67)</td>
</tr>
</tbody>
</table>

All means reported in kilograms.

4.4 Chest Press Repetitions to Failure (REPS)

Table 4 displays the means (+/- S.D.) for the dependent variable REPS for the Cr and P groups over time trials T1, T2 and T3. A 2 x 3 ANOVA analysis revealed the following:

a) a significant TRIAL main effect for REPS averaged across both the Cr and P groups (p<0.001)

b) a non-significant GROUP x TRIAL interaction effect for REPS between the Cr and P groups across the three time trials (p = 0.158).

To summarize, both the Cr and P groups significantly increased the number of
repetitions to failure they were able to perform on the chest press exercise (using the baseline 10 RM weight established at T1) over trials T2 and T3. This pattern of change was consistent for both groups, with no significant differences between the two groups for the number of repetitions at trials T2 and T3.

Table 4: Mean Values for Repetitions to Failure Test at T1, T2 and T3

<table>
<thead>
<tr>
<th>GROUP</th>
<th>TEST TRIAL</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T1</td>
<td>T2</td>
<td>T3</td>
</tr>
<tr>
<td>1. Creatine Group</td>
<td>10 (baseline)</td>
<td>*14.96 (+/-3.37)</td>
<td>*22.41 (+/-5.05)</td>
</tr>
<tr>
<td>2. Placebo Group</td>
<td>10 (baseline)</td>
<td>*14.42 (+/-3.16)</td>
<td>*20.23 (+/-4.62)</td>
</tr>
</tbody>
</table>

*  2 x 3 ANOVA: significantly different from baseline (p=0.05)

4.5 Grip Strength (GRIP)

Grip strength was measured at trials T1 and T3 only. Table 5 summarizes the results from these measurements for the Cr and P groups. A 2 x 2 ANOVA analysis revealed:

(a) a significant TRIAL main effect for GRIP averaged across all subjects (Cr + P) across the two trials (p<0.001)

(b) a non-significant TRIAL x GROUP interaction effect (P=0.999).

In summary, grip strength generally improved for all subjects over the six week intervention period (from T1 to T3) and this pattern of improvement did not differ
significantly between the Cr and P groups.

Table 5: Mean Values for Grip Strength at T1 and T3

<table>
<thead>
<tr>
<th>GROUP</th>
<th>TEST TRIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T1</td>
</tr>
<tr>
<td>1. Creatine Group</td>
<td>70.07 (+/-24.53)</td>
</tr>
<tr>
<td>2. Placebo Group</td>
<td>70.31 (+/-19.47)</td>
</tr>
</tbody>
</table>

* 2 x 2 ANOVA: significantly different from T1 (p=0.05)
All means reported in kilograms.

4.6 Strength Construct (STRENGTH)

Changes in body strength were determined via four individual strength measures including two upper body tests (CP and SR) and two lower body tests (LC and LE). These four tests incorporated the dominant primary and secondary, push-pull muscles of the body. Therefore, these recorded values were combined to form a STRENGTH construct which provided an assessment for change in whole body strength. The mean values (+/-S.D.) for each of these four tests across trials T1 and T3 are listed in Table 6.

A 2 x 2 MANOVA analysis was applied to test for significance between the Cr and P groups for the construct STRENGTH. Visual inspection of the data in Table 6 revealed mean performance for all four strength tests appeared to increase across all subjects (Cr + P) over trials T1 to T3. This observation was statistically supported by the MANOVA analysis.
which indicated:

(a) a significant main effect for TRIALS averaged across both groups between T1 and T3 (p<0.001)

(b) but a non-significant GROUP x TRIAL interaction effect (p=0.091).

In summary, STRENGTH significantly improved for all subjects from T1 to T3. Averaged across all four 10 RM strength tests these improvements equated to 31% and 25% for the Cr and P groups respectively. However, they were not significantly different between groups (p=0.09).

Table 6: Mean Values for the Four 10 RM STRENGTH Tests at T1 and T3

<table>
<thead>
<tr>
<th>GROUP</th>
<th>STRENGTH TEST</th>
<th>TRIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T1</td>
<td>T3</td>
</tr>
<tr>
<td>1.Creatine</td>
<td>Chest Press</td>
<td>67.22 (+/-30.07)</td>
</tr>
<tr>
<td></td>
<td>Seated Row</td>
<td>64.44 (+/-27.99)</td>
</tr>
<tr>
<td></td>
<td>Leg Curl</td>
<td>75.19 (+/-28.13)</td>
</tr>
<tr>
<td></td>
<td>Leg Extension</td>
<td>68.89 (+/-26.72)</td>
</tr>
<tr>
<td>2.Placebo</td>
<td>Chest Press</td>
<td>72.00 (+/-29.64)</td>
</tr>
<tr>
<td></td>
<td>Seated Row</td>
<td>73.73 (+/-31.96)</td>
</tr>
<tr>
<td></td>
<td>Leg Curl</td>
<td>76.38 (+/-27.32)</td>
</tr>
<tr>
<td></td>
<td>Leg Extension</td>
<td>68.27 (+/-24.53)</td>
</tr>
</tbody>
</table>

* 2 x 2 MANOVA: Significantly different from T1 (p=0.05)
All means reported in pounds.
4.7 Functional Ability Construct (FUNCTION)

Functional abilities were assessed via two unique measurements developed specifically for this investigation. The CR and the MB tests were used to evaluate functional strength and power in predominantly the lower and upper body, respectively. Together, these two tests gave an indication of overall functional ability of the body. Therefore, they were combined into a single construct “FUNCTION” and collaterally analysed. Rigorous reliability testing was not conducted for these novel test procedures prior to their use in this study. However, correlation analysis revealed that test, re-test reliability for each of these functional tests was high indicating that subjects maintained their relative ranking from the pre (T1) to the post (T3) testing sessions. Correlation values were 0.8473 and 0.8292 for the CR and MB tests, respectively. The mean values (+/-S.D.) for each of these tests across trials T1 and T3 are listed in Table 7.

A 2 x 2 MANOVA analysis was applied to test for significance between the Cr and P groups for the FUNCTION construct. The MANOVA analysis revealed:

(a) a significant main effect for TRIALS for all subjects between the two trials (T1 and T3, p<0.001)

(b) a non-significant TREATMENT x TRIAL interaction effect (p=0.600).

In summary, FUNCTION significantly improved for all subjects averaged across both treatment groups, from pre (T1) to post (T2) testing. However, these improvements were not significantly different between the Cr and P groups.
Table 7: Mean Values for the Two FUNCTIONAL Tests at T1 and T3

<table>
<thead>
<tr>
<th>GROUP</th>
<th>Test</th>
<th>TEST TRIAL</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Creatine</td>
<td>Chair Rise</td>
<td>20.24 (+/-.342)</td>
<td>*16.84 (+/-2.34)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Med-Ball Lift</td>
<td>13.11 (+/-2.42)</td>
<td>*11.38 (+/-1.74)</td>
<td></td>
</tr>
<tr>
<td>2. Placebo</td>
<td>Chair Rise</td>
<td>20.84 (+/-.326)</td>
<td>*16.98 (+/-1.75)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Med-Ball Lift</td>
<td>13.39 (+/-2.23)</td>
<td>*11.63 (+/-2.12)</td>
<td></td>
</tr>
</tbody>
</table>

* 2x2 MANOVA: Significantly different from T1 (p=0.05). All means reported in seconds.

4.8 Within Group Differences: Males vs Females

Although group differences were controlled for using stratified random sampling based on age, sex and activity level this does not exclude the possibility males and females within the treatment groups may have responded differently to supplementation. Table 8 displays the T1, T2, and T3 means (+/- standard deviations) for WT for both males and females from the two treatment groups. The means (+/- standard deviations) for CP, SR, LE, and LC for males and females from both the Cr and P groups for T1 and T3 are listed in Table 9. Visual inspection of this data appears to indicate that males and females may have responded differently to the creatine supplementation compared to placebo. To determine whether these differences were significant post-hoc comparisons using a SEX x GROUP x TRIAL ANOVA with repeated measures on the TRIAL factor (T1, T2, T3) was performed for WT and two separate SEX x GROUP x TRIAL MANOVA analyses with repeated measures on the TRIAL factor (T1, T3) were performed for the four 10 RM strength tests (STRENGTH construct) and the two functional tests (FUNCTION construct).
Table 8: Sex Differences Between Groups for Body Weight at T1, T2 and T3

<table>
<thead>
<tr>
<th></th>
<th>Creatine Group</th>
<th>Change</th>
<th>Placebo Group</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T1</td>
<td>T2</td>
<td>T3</td>
<td>(T1-T2)</td>
</tr>
<tr>
<td>Males: Body WT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body WT</td>
<td>82.93</td>
<td>*83.92</td>
<td>*83.96</td>
<td>*0.99</td>
</tr>
<tr>
<td>Females: Body WT</td>
<td>66.81</td>
<td>*67.37</td>
<td>66.57</td>
<td>*0.55</td>
</tr>
</tbody>
</table>

* Significant change from T1, p=0.05 (within group difference only)

All values are listed in kilograms.

Table 9: Sex Differences Between Groups for the 10 RM Strength Tests at T1 & T3

<table>
<thead>
<tr>
<th>Sex</th>
<th>Test</th>
<th>Creatine Group</th>
<th>Change</th>
<th>Placebo Group</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>T1</td>
<td>T3</td>
<td>(T1-T3)</td>
<td>T1</td>
</tr>
<tr>
<td>Males</td>
<td>1. CP</td>
<td>93.85</td>
<td>116.73</td>
<td>*22.88</td>
<td>95.00</td>
</tr>
<tr>
<td></td>
<td>(20.43)</td>
<td>(22.72)</td>
<td>(6.44)</td>
<td>(22.27)</td>
<td>(24.49)</td>
</tr>
<tr>
<td></td>
<td>2. SR</td>
<td>87.31</td>
<td>120.58</td>
<td>*33.27</td>
<td>98.85</td>
</tr>
<tr>
<td>Cr: n=14</td>
<td>(23.42)</td>
<td>(26.32)</td>
<td>(12.26)</td>
<td>(25.51)</td>
<td>(28.36)</td>
</tr>
<tr>
<td></td>
<td>3. LE</td>
<td>88.46</td>
<td>112.88</td>
<td>*24.42</td>
<td>84.23</td>
</tr>
<tr>
<td>Pl: n=13</td>
<td>(25.93)</td>
<td>(25.10)</td>
<td>(8.49)</td>
<td>(23.44)</td>
<td>(25.73)</td>
</tr>
<tr>
<td></td>
<td>4. LC</td>
<td>96.15</td>
<td>128.46</td>
<td>*32.31</td>
<td>96.23</td>
</tr>
<tr>
<td></td>
<td>(25.99)</td>
<td>(28.86)</td>
<td>(14.16)</td>
<td>(23.02)</td>
<td>(26.69)</td>
</tr>
<tr>
<td>TOTALS</td>
<td>365.77</td>
<td>478.65</td>
<td>**112.88</td>
<td>374.31</td>
<td>456.70</td>
</tr>
<tr>
<td>(89.56)</td>
<td>(95.88)</td>
<td>(31.72)</td>
<td>(85.55)</td>
<td>(96.75)</td>
<td>(21.93)</td>
</tr>
<tr>
<td>Females</td>
<td>1. CP</td>
<td>42.50</td>
<td>54.07</td>
<td>*11.57</td>
<td>49.00</td>
</tr>
<tr>
<td></td>
<td>2. SR</td>
<td>43.21</td>
<td>56.21</td>
<td>*13.00</td>
<td>48.62</td>
</tr>
<tr>
<td>Cr: n=13</td>
<td>(7.23)</td>
<td>(9.95)</td>
<td>(6.36)</td>
<td>(10.52)</td>
<td>(13.11)</td>
</tr>
<tr>
<td></td>
<td>3. LE</td>
<td>50.71</td>
<td>66.11</td>
<td>*15.90</td>
<td>52.31</td>
</tr>
<tr>
<td>Pl: n=13</td>
<td>(8.29)</td>
<td>(9.84)</td>
<td>(3.19)</td>
<td>(12.35)</td>
<td>(13.68)</td>
</tr>
<tr>
<td></td>
<td>4. LC</td>
<td>55.71</td>
<td>76.25</td>
<td>*20.54</td>
<td>56.54</td>
</tr>
<tr>
<td></td>
<td>(10.54)</td>
<td>(12.35)</td>
<td>(8.89)</td>
<td>(13.13)</td>
<td>(15.30)</td>
</tr>
<tr>
<td>TOTALS</td>
<td>192.13</td>
<td>253.14</td>
<td>*61.01</td>
<td>206.47</td>
<td>267.97</td>
</tr>
<tr>
<td>(28.13)</td>
<td>(34.87)</td>
<td>(16.18)</td>
<td>(43.57)</td>
<td>(48.98)</td>
<td>(14.19)</td>
</tr>
</tbody>
</table>

* Significant change T1-T3, p=0.05

** Significant difference between creatine and placebo groups, p=0.05

All values listed are in pounds.
The results from these analyses revealed the following for males and females from the Cr and P groups for the variable WT and the constructs STRENGTH and FUNCTION:

(a) a non-significant SEX x GROUP x TRIAL interaction for WT at T2 and T3 from T1 between the two treatment groups;

(b) a non-significant SEX x GROUP x TRIAL interaction for FUNCTION from T1 to T3;

(c) A significant SEX x GROUP x TRIAL interaction for STRENGTH (p=0.009).

In summary, the changes in body weight for the Cr males compared to the PI males at T1, T2 and T3 were not significantly different from the changes in body weight for the Cr females compared to the PI females from T1, T2, and T3. The improvement in functional ability from T1 to T3 was found to be consistent for both males and females across the two treatment groups. Finally, whole body strength (as assessed by the construct STRENGTH) was significantly improved for the Cr males over and above the improvements experienced by the P males while the difference in STRENGTH from T1 to T3 for the Cr females and the PI females was found to be consistent.
CHAPTER 5

5.0 DISCUSSION

5.1 Introduction

As expected the six week, high intensity resistance training program resulted in significant improvements in strength and functional ability in all subjects as evidenced by the positive changes observed in the dependent variables REPS, GRIP, and the constructs STRENGTH and FUNCTION which combined the CP, SR, LC, LE variables and the CR and MB variables respectively. Although visual inspection of the data from Tables 3, 4 and 6 suggests there were differences between the two groups for the variables WT, REPS, and STRENGTH in response to the resistance training program, statistical significance was not obtained between the Cr and P groups for any of these variables. This chapter will discuss these findings.

5.2 T1 to T2: Short-term Effects of Creatine Loading

Measurements for WT and REPS were recorded at T1, T2 and T3. The T1 measure established baseline values for all subjects. At T2, values for WT and REPS were re-recorded to determine whether the seven day Cr.H₂O loading phase (20 grams per day for seven days) had an immediate effect. Previous researchers have consistently reported that an initial rapid weight gain (averaging 1-1.5 kg) occurs immediately following the now standardised creatine loading phase (Balsom et al., 1993b; Earnest et al., 1995; Green et al.,
1996; Kreider et al., 1996; Kreider et al., 1997; Vandenberghe et al., 1997; Volek et al.,
1997). After seven days of loading, the Cr group in the present study experienced a mean
weight gain of .77 kg (compared to 0.21 kilograms in the P group). This gain is similar to
significant gains reported by other investigations but did not attain significance from the P
group in this study.

As mentioned, an immediate weight gain has been consistently reported in previous
research following a similar creatine loading protocol. Since direct measurement of creatine
retention in the body requires elaborate and invasive measurement procedures, it is common
for researchers to readily associate any rapid weight gain with enhanced retention of creatine
in the body following supplementation (Barnett et al., 1996; Earnest et al., 1995; Kreider et
al., 1996; Volek et al., 1997). Few researchers directly measure plasma and intramuscular
creatine levels following supplementation. The investigations by Harris et al. (1992), Green
et al. (1996), Hultman et al. (1996) and Vandenberghe et al. (1997) directly analysed blood
and muscle biopsy samples following supplementation. Moreover, Vandenberghe et al.
(1997) examined the relationship between increased retention and improved performance
during exercise. Each of the aforementioned investigations reported significant creatine
retention following the loading of 20 grams of Cr.H\textsubscript{2}O per day. Hultman et al. (1996)
demonstrated that a maintenance dose of 2-5 grams per day following the loading phase
would maintain elevated creatine stores for at least 30 days. Several researchers examining
creatine ingestion and performance have for logistics reasons, assumed that by using the
standard loading and maintenance protocol augmented creatine storage in muscle would
occur (Balsom et al., 1995; Barnett et al., 1996; Dawson et al., 1995; Earnest et al., 1995;
Kreider et al., 1996; Volek et al., 1997). The fact that so many studies have accepted these data as true is reflected by the many recent reports on creatine supplementation where direct measures of creatine retention have not been made, based on the previous reports of Hultman and his associates.

In the present investigation it is possible that enhanced creatine retention did not occur as a result of the supplementation protocol even though the procedures paralleled those from previous studies having reported positive results. Barnett et al. (1996) concluded from their investigation on the effects of Cr.H₂O loading and multiple sprint cycle performance that the loading phase may have failed to result in significant creatine retention. This alternate explanation was given due to the fact that their’s was the only study incorporating three or more repeated bouts of high intensity short term exercise demonstrating both no improved performance and no initial weight gain following creatine loading (see Chapter 3 conclusions).

In this investigation, support for the conjecture that the creatine loading protocol had at best, minimal effect on enhancing intramuscular creatine retention is further manifest in the results from T2 for REPS. From Table 4 it is clear that both the Cr and P groups made similar improvements by T2 for REPS. A difference from T1 of 4.96 repetitions and 4.42 repetitions for the Cr and P groups, respectively. Based on past research it was anticipated that the present investigation would have shown a significantly greater improvement in the REPS test for the Cr versus the P group following the loading phase.

Volek et al. (1997) reported that their creatine group performed a significantly greater number of repetitions to failure on all five consecutive sets of bench press (separated by two
minutes recovery) than their placebo group after six days of Cr.H$_2$O loading. Following 14 days of supplementation Earnest et al. (1995) also observed a significant improvement in repetitions to failure for the bench press exercise in a creatine supplemented group versus a placebo group using the pre-established 10 RM weight for each subject.

There are at least two possible answers that may explain the lack of significant difference between the Cr and P groups following supplement loading in the present study. Creatine retention following supplementation may have been enhanced in the muscles of the Cr group with little or no ergogenic effect or remained effectively unchanged.

The absence of any significant weight gain in the creatine-supplemented group supports the suggestion that retention was not enhanced. On the other hand, it is possible that the standard loading protocol may not be effective in increasing intramuscular creatine stores for this unique population or differences in response to loading exist between subjects within each group (i.e. males versus females). Perhaps the time course for enhanced creatine retention and/or the resulting beneficial effects may be different from that experienced by much younger, usually active individuals studied exclusively in previous investigations. As this is apparently the first investigation to explore the effect of creatine supplementation and resistance training with older adults and little is known about the exact mechanisms by which supplemental creatine exerts its ergogenic effect, a definitive explanation for the short term results from this investigation is impossible.
5.3 TI - T3: Long-Term Effects of Creatine Loading and Maintenance

Statistical analyses of the results for the dependent variable GRIP and the constructs STRENGTH and FUNCTION revealed that six weeks of high intensity resistance training in conjunction with creatine supplementation did not result in significantly greater performance on these measures over the placebo group.

5.3.1 Grip Strength

Grip strength significantly improved by 1.38 kilograms between T1 and T3 for both the Cr and P groups with no difference between treatments (see Table 5). Grip strength was included as a dependent variable since it is frequently included as a standard measurement tool for the assessment of changes in muscle strength following resistance training (MacDougall et al., 1991; McArdle et al., 1986).

Only one other investigation involving creatine supplementation employed a grip strength test in its methodology. Tarnopolsky et al. (1997) studied the effects of Cr.H$_2$O supplementation in patients with mitochondrial cytopathies. Subjects performed a one-minute ischemic isometric hand grip exercise using a standard hand grip dynamometer. Following Cr.H$_2$O supplementation, subjects significantly increased force output during the one-minute test. This study did not involve any form of exercise intervention during the supplementation period. However, comparing the results from the study of Tarnopolsky et al. (1997) to the present study is problematic since we used a brief forearm contraction to generate a maximum force, as opposed to a sustained one-minute contraction in the former study.
It may be suggested that a null effect of creatine supplementation on grip strength in the present study could arise from one of the following: a) creatine was not retained in the muscles of these subjects; b) creatine concentration was enhanced, but its effect was not apparent during a brief maximum gripping effort.

5.3.2 STRENGTH and FUNCTION Constructs

The hypothesis that Cr.H₂O supplementation combined with six weeks of high intensity resistance training would significantly improve the strength and functional abilities in both older adult males and females above improvements expected with resistance training alone was not supported by the present investigation. However, as expected all subjects improved significantly for all tests within these two constructs. From T1 to T3 the Cr and P groups experienced approximately 15% and 16% improvements, respectively for FUNCTION and 31% and 25% improvements, respectively for STRENGTH. Therefore, this report does provide strong support for the use of resistance training to improve both whole body strength and functional ability in males and females between the ages of 50 to 75.

The mean scores reported in Table 7 indicate all subjects improved on both the CR and MB tests from T1 to T3 with no significant difference in the absolute level of improvement between treatment groups. This magnitude of improvement is in agreement with results reported by other researchers using similar subjects following similar protocol (Fiatarrone et al., 1990; Greig et al., 1994; Skelton et al., 1995). However, it is important to remember when measuring performance changes over time in a repeated measures experimental design it is difficult to insulate the testing results from the learning effect. To
minimize data contamination due to a learning effect in the present investigation the following measures were adapted.

For both functional tests subjects were given a verbal description and visual demonstration by the author followed by a single, non-timed trial attempt in which they performed the actual timed test. Subjects were then instructed not to attempt or mimic the test procedures for either of these two tests during the entire six week intervention period until after they had been re-tested at T3. Evidence that subjects adhered to this instruction was provided at T3 since at that time no subjects were able to recall the protocol for either test and once again required a complete verbal description, visual demonstration and a non-timed practice attempt before completing their T3 trial. Therefore, it is the authors contention that if a learning effect did occur it likely accounted for very little of the improvement seen from T1 to T3 for these two tests. It is more plausible that the improvements were due to adaptations that occurred as a result of the resistance training program including the significant increase in muscular strength which occurred with all subjects.

Functional testing is usually reserved for measurement in older, sedentary, often frail elderly persons (Bosscher and Hanneke Van Der, 1995; Greig et al., 1994; Skelton and Young, 1993). The functional tests used in this study were developed with our specific demographic range in mind. Therefore, the tests were much more demanding requiring a higher level of muscle power, co-ordination and balance than are normally required by standard functional tests for older adults (Fiatarone et al., 1994). These tests were essentially a race against time using body weight only (CR test) and body weight plus minimal external loading (MB test). Therefore, muscle power more than muscle strength (or
endurance) was a determining factor in performance.

It was originally hypothesized that those subjects receiving creatine supplementation would demonstrate a greater degree of improvement for the CR and MB tests than would those receiving placebo following six weeks of resistance training. As mentioned the results of this investigation reject this hypothesis since a significant difference for either test from T1 to T3 was not observed between the two treatment groups. This lack of significant difference between groups was thought to be related to the fact that the improvements observed in whole body muscular strength for all subjects as defined by the STRENGTH construct (see Table 6) were not significantly different between groups.

Power is a function of strength since power is equal to work (force x distance) divided by time and force and strength are essentially equivalent (maximum amount of resistance applied). Muscle power will improve for individuals partaking in regular high intensity resistance training especially those with limited or no resistance training experience (Bompa, 1983, McArdle et al 1986). In the present investigation it was hypothesized that if resistance training combined with creatine supplementation resulted in greater improvements in muscular strength than resistance training alone (as was reported by Vandenberghe et al, 1997), this greater level of strength improvement might be sufficient to result in a greater level of functional improvement in those receiving creatine compared to those receiving placebo. However, STRENGTH did not improve significantly for the Cr group compared to the P group. Therefore, the lack of significant difference for FUNCTION between the two groups would be expected. This initial conclusion was supported by the non-significant results from the MANOVA analysis performed on the FUNCTION construct (see Table 7 in
Chapter 4). However, the next section which deals with gender differences in response to supplementation will show that this initial conclusion is insufficient.

Of all the dependent variables measured during this investigation the four 10 RM strength tests (which define the STRENGTH construct) were expected to show the greatest degree of difference between the Cr and P groups after six weeks of training. This hypothesis was based on recent but limited published evidence supporting the use of Cr.H$_2$O supplementation combined with resistance training. As was previously reported, creatine supplementation often results in an increase in the concentration and availability of PCr in the muscle. This may bolster strength improvements resulting from resistance training by allowing for a greater volume and intensity of training in a given period of time. One or more of the following mechanisms may be responsible: a more rapid replenishment of ATP between sets and repetitions; a more rapid rate of PCr resynthesis between sets and repetitions; enhanced buffering of hydrogen ions leading to a lesser decline in muscle cell pH. Alternatively, creatine supplementation may also exert a positive influence on muscle cell hypertrophy via an increased rate of protein synthesis as has been suggested previously.

Ingwall (1976) examining the in-vitro effects of creatine on increased muscle mass following exercise found that an increase in the concentration of intracellular creatine resulted in increased rates of synthesis for both myosin heavy chain and actin myofibrillar proteins in both cardiac and skeletal muscle. Indeed, Sipila et al. (1981) also provided strong evidence that creatine supplementation had a pronounced effect on protein synthesis. Studying the effects of creatine supplementation as treatment for gyrate atrophy of the choroid and retina, a disease characterized by atrophy of Type-II (fast twitch) skeletal muscle
fibres they observed that one year of low dose supplementation (1.5 grams/day) resulted in a significant increase in the diameter of Type II muscle fibre in the absence of any from of resistive exercise.

The investigation by Vandenberghe et al. (1997) is one study that directly examined the effects of creatine supplementation on performance in conjunction with a longitudinal resistance training program. Earnest et al. (1995) studied the effects of 28 days of supplementation on experienced weight trainers. However, while their subjects were likely weight training at the time, the type of training they were involved in was not standardized or specified. Both of these studies demonstrated significant strength benefits as a result of supplementation. Kreider et al. (1996) examined body composition changes but no performance changes in experienced weight trainers following 28 days of Cr.H2O supplementation in conjunction with resistance training. They concluded that lean body mass significantly increased as a result of creatine supplementation.

Based on information provided by these investigations and knowledge of the proposed mechanisms by which creatine is speculated to exert its ergogenic effects, it was hypothesised that STRENGTH would increase to a significantly greater extent for subjects in the Cr compared to the P group. This was not observed, but may be accounted for by one or more of the following. First, as mentioned throughout this discussion the supplementation protocol may have failed to sufficiently increase the concentration of intracellular creatine. Once again, evidence is provided from the first part of this study in which no apparent short-term effect of the Cr.H2O loading phase was observed. If this explanation is to be accepted, then one of the following events might have occurred: (1) A larger than expected number of
individuals in the Cr group must have been “non-responders”. Several researchers have indicated that approximately 20-30% of individuals who ingest supplemental creatine experience a minimal increase of creatine uptake into the body (Balsom et al., 1994; Greenhaff et al., 1993; Greenhaff, 1995); (2) The supplemental protocol may have been insufficient to enhance creatine stores in an older adult population. While highly speculative, this explanation may have merit in light of the fact that after about the age of 50 both men and women experience a decline in the number and size of type II muscle fibres at the rate of approximately 1.5% per year ([Danneskiold-Samsoe et al., 1984; Skelton et al., 1994). Theoretically, some of the subjects in this investigation could have lost as much as 30% of these fibres as the upper limit of the age range studied was 75 years. Thus, the changes in creatine retention following supplementation, as reported in previous research using younger subjects, might be unrealistic with the present group.

Second, it is possible that within the two groups subjects responded differently to supplementation and training. Initial stratified sampling statistically equalized both treatment groups on age, sex, and activity level. However, this does not preclude the chance that individuals within the Cr group may have responded differently to this active substance. In order to test this hypothesis separate post-hoc ANOVA analyses for the variable WT and the construct STRENGTH and FUNCTION were conducted within and between the two treatment groups with separate comparisons made between males only, females only, those with no resistance training experience (activity level 1), and those with weight training experience (activity levels 2 and 3). Only the three above dependent variables were included in the analyses since they would give an indication of both short term (WT) and longer term
effects (STRENGTH and FUNCTION). These analyses revealed interesting results.

5.4 Within Group Differences

The separate analyses for the two levels of activity revealed there were no differences in WT, FUNCTION or STRENGTH either within or between the two treatment groups in response to supplementation. Therefore, it was concluded that individuals with varying levels of resistance training experience responded to supplementation (either Cr or P) in the same manner. There is currently no literature of which we are aware, suggesting individuals respond differently to creatine supplementation depending upon training experience.

The separate analyses for WT and STRENGTH for males and females both within and between the Cr and P groups revealed that strength differences as a result of resistance training and creatine supplementation did occur between the two sexes.

Table 8 lists the means for body weight for males and females from T1, T2 and T3 for both the Cr and P groups. Of interest is the observation that males within the Cr group experienced a significant weight gain at T2 over baseline and this remained significant at T3. These differences were 0.99 kg and 1.03 kg respectively, for T2 and T3. For the females in the Cr group and both males and females in the P group weight did not vary significantly from baseline at either T2 or T3 compared within each gender and treatment condition only. Cr males experienced a significant change in body weight from baseline at both T2 and T3. However, when compared to males in the P group these differences were not significant.

The approximate one kilogram change in body weight experienced by the Cr group males at T2 and T3 is in direct agreement with values reported by previous researchers.
whose subjects on average experienced a significant weight gain of 1-1.5 kg following the creatine loading and/or the loading plus maintenance (Earnest et al., 1995; Kreider et al., 1996; Kreider et al., 1997; Vandenberghe et al., 1997; Volek et al., 1997). Considering the Cr males weight gain in the present study was not significantly different from the changes seen in the males from the placebo group at T2 and T3, it must be concluded that creatine supplementation did not significantly effect short term or longer term measurements for body weight. Therefore, we must also maintain that if enhanced retention following creatine retention is marked by a statistical difference in body weight, then it is likely that the present supplementation protocol did not significantly increase intramuscular creatine stores.

The analysis for whole body strength using the STRENGTH construct provides the only significant evidence in the present investigation for an ergogenic effect of Cr.H₂O supplementation. From Table 9 we can see that in terms of strength gains, males responded differently to creatine supplementation when compared to males in the placebo group while females from the two treatment groups did not differ. The means for each strength test, the overall totals for T1 and T3, the differences between T1 and T3 and the summed total changes for all four tests (all in pounds) are presented in Table 9. It is once again clear that the resistance training program resulted in significant improvements in whole body strength in all subjects, both males and females regardless of supplementation. However, the relevant observation from this data for the present study is the Cr group males experienced a significant improvement in STRENGTH over males from the P group. These changes were approximately 31% for the Cr group males compared to 22% for the P males (the Cr and P females improved approximately 32% and 30% respectively).
The reasons for the response variation between males and females to creatine supplementation are not readily apparent since literature concerning this issue is very limited. A small number of investigations have examined the effects of supplementation on performance using both males and females (Jacobs et al., 1997; Mujika et al., 1996; Redondo et al., 1996). None of these however, made within group (CR and P) comparisons of males and females so it is not known whether differences existed but were not identified or reported. Only the report by Jacobs et al. (1997) reported a beneficial effect on performance following creatine supplementation using both male and female subjects (their Cr group consisted of 11 males and 3 females and the P group, 10 males and 2 females).

The recent study by Vandenberghe et al. (1997) explored 10 weeks of Cr.H2O supplementation combined with resistance training on performance in a group of 10 females compared to 9 females receiving placebo (all sedentary, between 19-22 years). They discovered both intramuscular Cr retention and performance were enhanced significantly in the Cr group. In contrast to these findings are the earlier observations by Forsberg et al. (1991). They performed a cross-sectional analysis on men and women ages 19-85 years examining total creatine content in the quadriceps muscle and found women to have significantly greater total creatine concentrations in relation to dry tissue weight than men. The contrast is due to the earlier observation that retention following supplementation is dependent upon the pre-supplemental intramuscular creatine concentration such that those with the highest initial values for total creatine content elicit the least (or no) significant change in creatine stores (Balsom et al., 1994; Harris et al., 1992; Volek and Kraemer, 1996).

Taking into account these limited observations the following explanations are given
for the differences seen in the present study between the males and females for the construct STRENGTH.

There is the chance that males and females do not respond to supplementation in the same manner. Although this claim is refuted by the results of Vandenberghe et al. (1997), there is evidence suggesting that women may have higher initial levels of intramuscular creatine (Forsberg et al., 1991). Therefore, in response to supplementation they may not experience an increase in muscle total creatine concentration. In this event it is unlikely they would experience either the short term effects or longer term effects on body weight and/or performance. Related to this is the possibility that older females may not respond to supplementation the same as their male counterparts. Keeping in mind that Vandenberghe et al. (1997) used females 19-22, Forsberg et al. (1991) studied women 32-70 years old, and the present investigation studied women between the ages of 50-75, it is then within reason to speculate that the women in this investigation may have had higher initial total intramuscular creatine levels than the males. If this premise were true it provides at least one viable explanation for the observation that our female subjects in the Cr group experienced neither changes for WT in the short term or for WT and STRENGTH in the long term and for the observation that Cr males experienced a significant change from baseline for WT and a significant improvement in STRENGTH over and above those seen for the males in the P group. However, this explanation will remain speculative until such time as it is researched thoroughly.

Performances on the two assessments for functional ability, besides being unaffected by activity level, were also consistent across sexes within and between treatment groups.
Therefore, in light of the post-hoc analysis revealing differences in strength between males and females in response to creatine supplementation and resistance training the initial conclusion that performance on the two functional tests was not significantly different between groups due to a non-significant difference in strength improvement, must be discarded.

Males in the Cr group demonstrated an approximate 10% significant improvement in STRENGTH over the males in the PI group following the six weeks of supplementation and resistance training (31% and 21% total improvement respectively). If strength and functional ability exhibited a perfect linear relationship than it would be expected that functional ability should also have improved for the Cr males by 10%. This was not the case. In fact, all subjects (males and females from both groups) experienced an approximate 15% increase in FUNCTION with no significant difference observed between groups or across the two sexes. Therefore, an alternate explanation is required to account for the lack of significant difference in the improvements for functional ability.

As mentioned previously the functional ability tests used in this investigation required a higher degree of muscle power than muscle strength to perform. However, since previous researchers have reported improvements in similar functional tests in older adults following resistance training it was hypothesized that in the present investigation this observation would be paralleled. Studies by Fiatarrone et al. (1990), Grieg et al. (1994), Fiatarrone et al. (1994) and Skelton et al., (1995) have all reported improvements in strength and functional ability following resistance training and have concluded, and in some cases demonstrated statistically that the improvements in functional ability were highly correlated
to the strength gains made. However, the subjects used in these investigations were all over the age of 70 and were classified as sedentary, inactive and/or frail elderly people. For these individuals it was likely that the main limiting factor for functional movement was muscle strength.

In the present study all subjects were active adults between the ages 50-75 years. For these individuals, functional ability is likely not limited by muscle strength. Although the improvements in strength probably accounted for some of the improvement seen in the tests for functional ability other factors likely played a role including neuromuscular properties related to muscle balance and coordination.

During the initial stages of any resistance training program there is a high degree of neuromuscular adaptation occurring. It has been established previously that these early adaptions can improve strength and functional ability even before substantial changes in the actual contractile component of the muscle have occurred (Bompa, 1983). For the specific demographic group studied in the present investigation it is possible that the improvements in FUNCTION as measured by the CR and MB tests may have been more a function of these early neuromuscular adaptions to training and less related to the changes that occurred in muscle strength. Therefore, since functional ability relies on only a minimal amount of base strength (Skelton and Young, 1993) for the subjects used in this investigation it is conceivable that strength was not a limiting factor during these tests. This could explain why all subjects experienced approximately the same level of improvement for the FUNCTION construct.
6.0 Summary, Conclusions and Recommendations

6.1 Summary

The purpose of this investigation was to explore the effects of creatine monohydrate supplementation combined with high intensity resistance training on the strength and functional abilities of males and females aged 50-75 years. 53 subjects were randomly assigned to either a creatine (Cr) or placebo (P) supplemented group and orally administered the appropriate substance for 1 week at 20 grams per day followed by five weeks at 5 grams per day. Supplementation was administered in conjunction with a six week, three session per week, whole body resistance training program. The dependent variables body weight (WT), and maximum repetitions to failure in the chest press exercise using a pre-determined 10 RM maximum weight (REPS) were measured at baseline (T1), after the first week of supplementation and training (T2) and immediately upon completion of the entire six week intervention period (T3). The variable grip strength (GRIP), the two functional variables chair rise and medicine ball lift (combined to form the construct FUNCTION) and the four 10 RM strength tests (combined to form the construct STRENGTH) were measured at T1 and T3 only.

Hypothesis testing involving separate ANOVA and MANOVA procedures revealed that while all subjects significantly improved their performance in the REPS, GRIP, STRENGTH and FUNCTION tests as a result of the resistance training program the changes
were not statistically different between groups. It was hypothesized, as evidenced by the non-significant immediate change in body weight at T2 and T3 that the supplementation protocol either had minimal effect on enhancing intramuscular creatine stores and/or creatine supplementation may not have had an ergogenic effect in this segment of the population similar to that previously observed in younger subjects following similar supplementation and resistive training.

Post-hoc MANOVA and ANOVA procedures revealed differences in the response to supplementation between the males and females within the Cr group. It was demonstrated that Cr males experienced a significant change in body weight from baseline at T2 and T3 and a significant change in STRENGTH from baseline, at T3. While the change in STRENGTH was significantly different from the P males the change observed for WT was not. The reasons for the lack of change seen for the females in the Cr group are not clear and may be related to gender differences in intramuscular creatine concentrations.

6.2 Conclusions

1. One week of creatine monohydrate loading (20 grams per day) followed by five weeks of a maintenance dosage (5 grams per day) in conjunction with six weeks of high intensity resistance training had no significant effect when statistical analyses combined the results from males and females in each treatment group on body weight, hand grip strength, chest press repetitions to failure, the FUNCTION construct (which included the chair rise and medicine ball lift tests) and the STRENGTH construct (which included the 10 RM strength tests - chest press, seated row, leg extension and leg curl) above that expected with
resistance training alone.

2. During the same period creatine supplementation was found to affect males and females differently such that males receiving creatine supplementation experienced a significant improvement in strength over the males in the placebo group and also experienced a significant increase in body weight compared to their own baseline measure but non-significant compared to P group males.

3. Females in either the creatine or placebo groups did not differ significantly on any of the variables measured throughout the study period.

6.3 Recommendations

The following recommendations for future research are made in order to clarify issues raised by the results of this investigation:

1. Cross-sectional research to determine if differences exist in the intramuscular concentrations of total creatine between males and females in general and between males and females at different ages.

2. Longitudinal study involving direct measures of plasma and muscle creatine concentrations, to examine the responses to resistance training in combination with creatine supplementation in males and females in general and of different age ranges.
BIBLIOGRAPHY


APPENDIX

A: Stratified Sampling Statistical Analyses

B: Resistance Training Program Exercises

C: Reliability Testing

D: Descriptions of 10 RM Strength Tests and Repetitions to Failure Test

E: Raw Data
Appendix A: Stratified Sampling Statistical Analysis

T-test Analyses Tables:

1. T-tests: Activity Level - for independent samples of treatment

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(Mean difference = -0.228)  T-test for equality of means

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2. T-tests: Sex - for independent samples of treatment

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Appendix B: Resistance Training Program Exercises

1. Chest Press

Prime Movers: Pectoralis major, triceps
Assistors: Anterior deltoid, pectoralis minor, latissimus dorsi, medial deltoid

2. Low Row

Prime movers: Latissimus dorsi, rhomboids,
Assistors: Trapezius, bicep brachialis, posterior deltoid

3. Pulldown

Prime movers: Latissimus dorsi, Rhomboids,
Assistors: Trapezius, bicep brachialis, teres major, serratus

4. Bicep Curl

Prime Movers: Biceps
Assistors: Biceps brachialis

5. Tricep Dip

Prime Movers: Triceps
Assistors: Anterior deltoid, pectoralis major

6. Overhead Press

Prime Movers: Deltoids
Assistors: Triceps, trapezius

7. Hamstring Curl

Prime Movers: Semi-tendonosous, bicep femoris, semi-membranosous
Assistors: Gracilus

8. Leg Extension

Prime Movers: Rectus femoris, vastus lateralis, vastus medialis, gluteus maximus
Assistors: Tensor faciae latae, popliteal, sartorius.
Appendix C: Reliability Testing

1. Chair Rise Test (CR)

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Paired Differences

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95% CI = (.896, 1.906)

2. Med-Ball Lift Test (MB)

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95% CI = (.789, 1.794)

3. Body Weight (WT)

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95% CI = (.789, 1.794)
4. ANOVA Analysis for Grip Strength (GRIP)

-8 cases accepted, 0 rejected due to out of range factors or missing data
-Tests involving “TRIAL” within subject effect
-AVERAGED tests of significance for GRIP using UNIQUE sums of squares

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Appendix D:

Descriptions of 10 RM Strength Tests and Repetitions to Failure Test

STRENGTH TESTS

Seated Row (SR)

There are two seat adjustments on the Low-Row machine. One for seat height, the other for arm reach. With the subject seated forward on the machine, seat height was adjusted so the subject's feet were flat on the floor with the legs bent between 75-90 degrees at the knee. Arm Reach was adjusted so when sitting at the proper seat height with the chest touching the front chest pad, the outstretched arms reached far enough forward to allow the finger tips to just touch the hand grips on the movement arm. Each repetition for the 10 RM test started with the subject holding the hand grips with the arms fully stretched to the front. The subject then pulled the movement arm fully back in one motion until the hands reached a point past the chest pad, adjacent to the upper body with the arms bent at the elbow approximately 90°. For all ten repetitions subjects maintained contact between their chest and the chest pad.

Chest Press (CP)

For the CP machine there is only one adjustment for seat height. With the subject sitting forward on the machine with their spine flat against the seat back, seat height was adjusted so that their feet were flat on the floor and the hand grips were just below the shoulder at the mid-sternum level. For each repetition subjects began with their hands holding the hand grips and the arms bent at the elbow and parallel to the floor so the hands were positioned approximately one inch in front of the shoulder. The subject then pushed the movement arm forward in one motion until the arms were fully extended with the spine remaining flat against the seat back. For each repetition the arms returned to the starting position before initiation of the next repetition.

Hamstring Curl (LC)

In the seated position on the Hamstring Curl machine adjustments for seat back level, and Achilles pad placement were made. The seat back adjustment was set so the subject's lower legs conformably hung at the knee, off the front of the seat with the low back flat against the seat back. The axis of rotation at the knee joint was visually aligned with the axis of rotation (bearings) of the movement arm. Next, the Achilles pad was placed against the posterior of the lower legs and the pad adjusted until it was at the level of the rear of the ankle joint (approximately where the Achilles tendon can be easily palpated). A thigh pad was lowered across the top of the lower thighs and "clicked" in place to decrease the effects of excessive leg and upper body movements. This machine has a range of motion limiter which protects against hyperextension of the knee. It was set at 10 degrees for maximal
comfort and safety. The subjects' arms were controlled during the test by having them hold the stationary hand grips at either side of the machine. Each repetition started with the subjects' knees extended out in front at the pre-set 10 degrees. They then proceeded to flex the legs at the knees, pulling the movement arm down and underneath them until it tapped the stopping device at the end of the movement. At this point the legs were bent at approximately 90° at the knees. The movement arm was then returned to the top/extended position and the movement repeated. Subjects maintained a firm grip on the stationary handholds and a flat lower back against the seat back for all repetitions.

**Leg Extension (LE)**

For the seated Leg Extension subjects sat on the seat and adjusted the seat back so their knees were visually aligned with the axis of rotation (bearings) of the movement arm the same as was described for the Hamstring Curl machine. With the knees properly aligned the subject then tucked their feet in behind the shin pad with the knees bent at approximately 90° and the thickness of the pad resting comfortably against the shins just above the ankle joint. Subjects were then instructed to maintain a straight low back keeping it in contact with the back pad at all times and to firmly grip the handles located at either side of the machine. Each repetition consisted of the subject extending both legs at the knee from the bent 90° position until the legs were straight out in front of the body with the knees at approximately 180° with the buttocks and low back maintaining firm contact with the seat. The legs were then returned to the bent knee position and the movement repeated.

**REPETITIONS TO FAILURE (REPS)**

This was a repetitions to failure test for the Chest Press following the same test protocol previously described (See CP). At T1 a 10 RM was established for this test. For the REPS test the ten repetitions was considered baseline and thus was the same for all subjects. At T2 and T3 subjects were asked to perform as many repetitions to complete muscle fatigue on this exercise using the same 10 RM weight that they initially recorded at T1. The test was terminated when the subject could no longer move the movement arm through the full range of motion and/or when the subject rested the movement arm at the top or bottom of the movement for longer than one second. Only one trial for this test was performed and the number of repetitions using proper form was recorded.
Table 10: Creatine Group Raw Data (Note; Males = #1-#13, Females = #14-#27)

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* WT values listed pounds, GRIP values in kilograms, CR and MB values in seconds and Strength values are a summation (in pounds) of the four, 10 RM strength tests including chest press, seated row, leg extension and leg curl.
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* WT values listed pounds, GRIP values in kilograms, CR and MB values in seconds and Strength values are a summation (in pounds) of the four, 10 RM strength tests including chest press, seated row, leg extension and leg curl.